December 10, 1980

Mr. Maxwell Lippitt, Jr.
Code 712
Naval Coastal Systems Center
Panama City, Florida 23406

Title: Effects of Contaminants on CF200 Diving Suit Material.

Attention Receiving Officer

Dear Mr. Lippitt:

Final Report on Evaluation of Physical Property Changes to CF200 Dry Suit Material When Subjected to Sea Water Contaminants

This is the Final Report on the evaluation of the "CF200" diving suit material. The objective of this research was to establish the degree of change in the physical properties of CF200 after it was subjected to acute exposures of contaminant solutions for varying periods of time.

The assumptions and procedures which we made and followed for the conduct of this research are discussed briefly in Appendix A. The results are presented in a matrix format in Appendix B and are plotted in Appendix C. Unfortunately, the samples of tested fabric were discarded, so we cannot include them.

We have enjoyed working on this interesting task and look forward to any other opportunities for research which may come along in the future. If you have any questions or comments concerning this research, please contact me at (614)424-7663.

Sincerely yours,

Brian Christenson
Research Engineer
Equipment Development

BCC:djs

Attachments

APPENDIX A

ASSUMPTIONS AND PROCEDURES USED IN CF200 EVALUATION

CF200

CF200 is a crushed synthetic rubber foam which is sandwiched between two layers of knit nylon fabric. The crushed foam provides thermal insulation and the knit fabric provides strength and abrasion resistance. The knit nylon fabric is bonded to the rubber with an adhesive. The specific type of adhesive that is used is proprietary information of the vendor which he would not release to Battelle.

All but one of the evaluations were done using new, unseamed CF200 sheet obtained from Diving Unlimited in San Diego, California. The last evaluation was performed (using MEK as a contaminant) on used, seamed CF200 which was cut from two diving suits.

Evaluation Methods

Degree of Deterioration

The degree of deterioration of the CF200 was measured with peel and tensile tests. The peel test, which was similar to ASTM D1876-72, measured the deterioration of either the crushed foam or the bond between the fabric and the foam; the tensile tests basically measured the deterioration of the nylon fabric.

Figure A-1 shows a schematic of the peel test. The grips moved apart at a rate of 5 inches per minute. Figure A-2 shows a peel test being performed. A tensile test, which was performed with the same machine and on the same size specimens, is shown in Figure A-3.

Rate of Deterioration

The rate of deterioration was measured by performing the peel and tensile tests at three different times after the fabric samples were immersed in a contaminant. The tests were made before immersion (to establish a baseline) and then after one minute, two hours, and a simulated six months after being immersed. The selection of these times is supported by the scenario at the end of this Appendix.

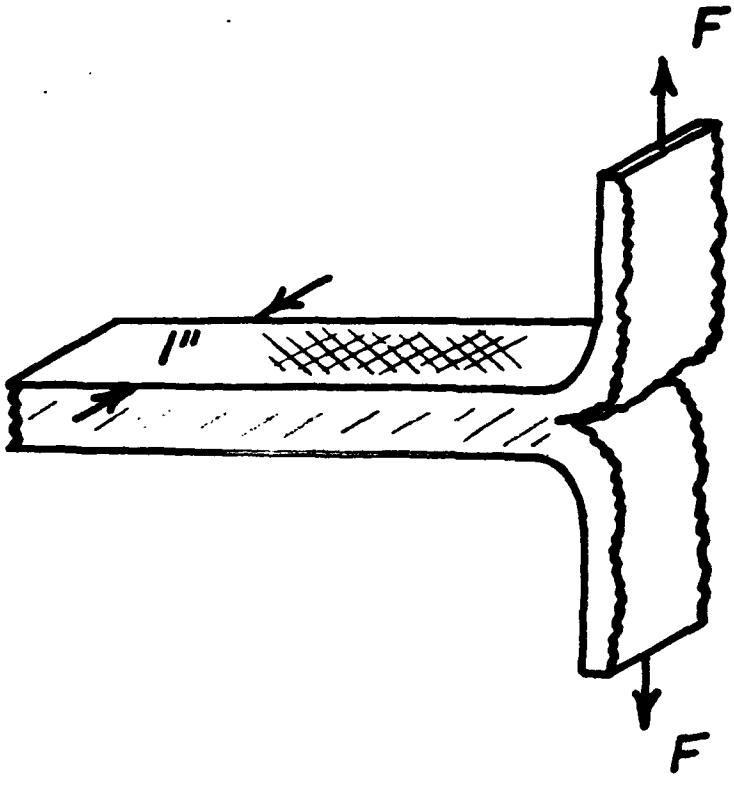

FIGURE A-1. PEEL TEST (AFTER ASTM D1876-72).
GRIPS MOVE APART AT 5 INCHES PER MINUTE.

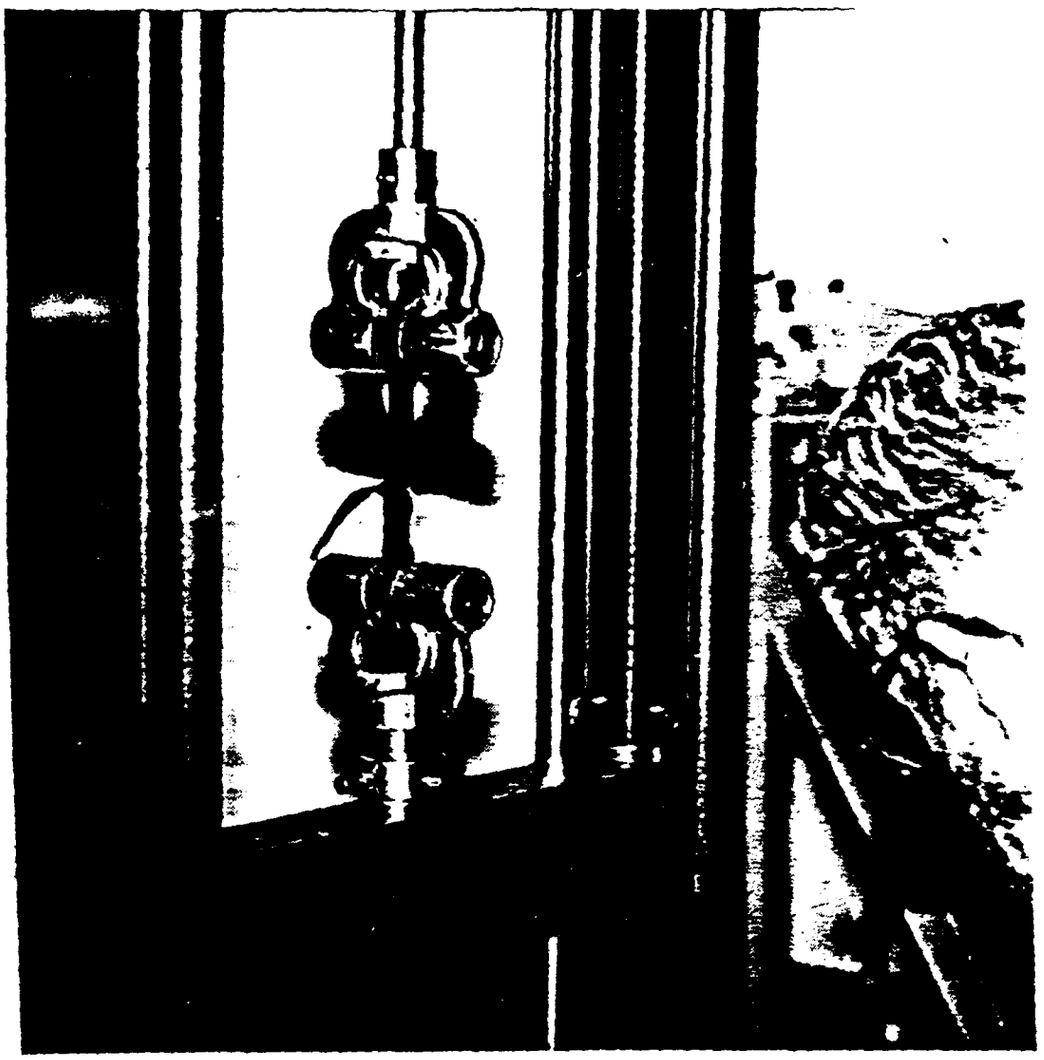

FIGURE A-2. PEEL TEST

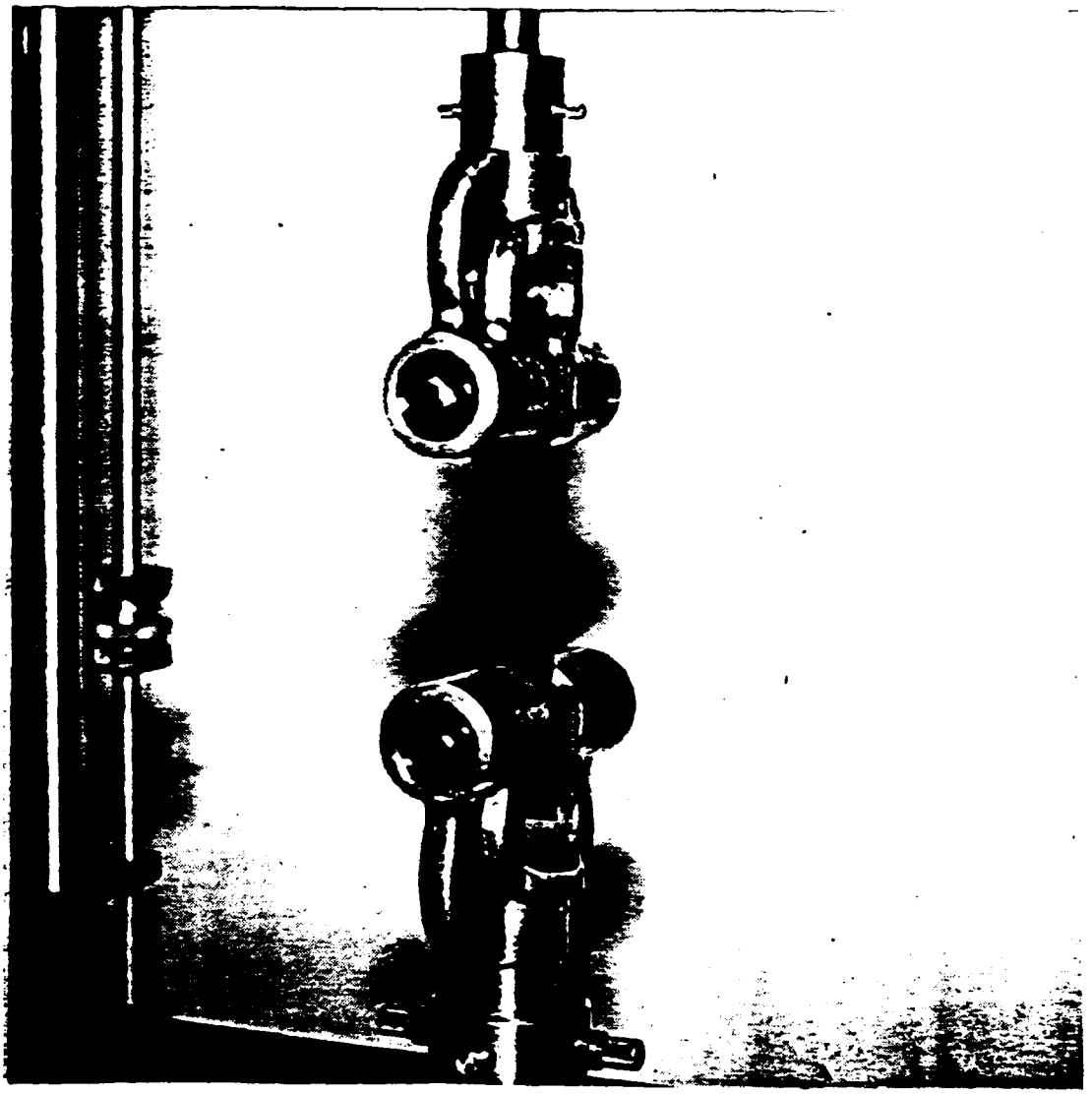

FIGURE A-3. TENSILE TEST

Evaluation Procedure

The material was cut into 6 x 24-inch swatches. A consistent orientation of the fabric knit was maintained. Each swatch was dedicated to a single contaminant and provided 24 identical 1 x 6-inch fabric samples which were used as follows for each contaminant:

- Six samples were left uncontaminated; three of these were tensile tested and three were peel tested, all at room temperature. (Establishing the uncontaminated tensile and peel strengths for each swatch eliminated possible variations in the material properties from one swatch to another.)
- The remaining 18 samples were immersed in an undiluted contaminant at room temperature for one minute and hung up. Figure A-4 shows several samples being immersed.
- After one minute, three of the contaminated samples were tensile tested and three were peel tested, all at room temperature.
- After two hours, three of the contaminated samples were tensile tested and three were peel tested, all at room temperature.

If either the tensile or the peel strengths had fallen below 10 or 15 percent of the uncontaminated strength at this point, the simulated 6 month evaluation was not performed, since a failure was considered to have occurred.

- The remaining six samples underwent an accelerated evaluation, using a 140° F temperature sustained for 288 hours (12 days). Three of these were tensile tested and the last three were peel tested.

Figure A-5 shows the expedient oven in which the foil-stoppered glass test tubes that held the samples were stored during the 12 days. The temperature inside the oven was maintained by air from a hot-air gun.

FIGURE A-4. FABRIC SAMPLES BEING IMMERSED

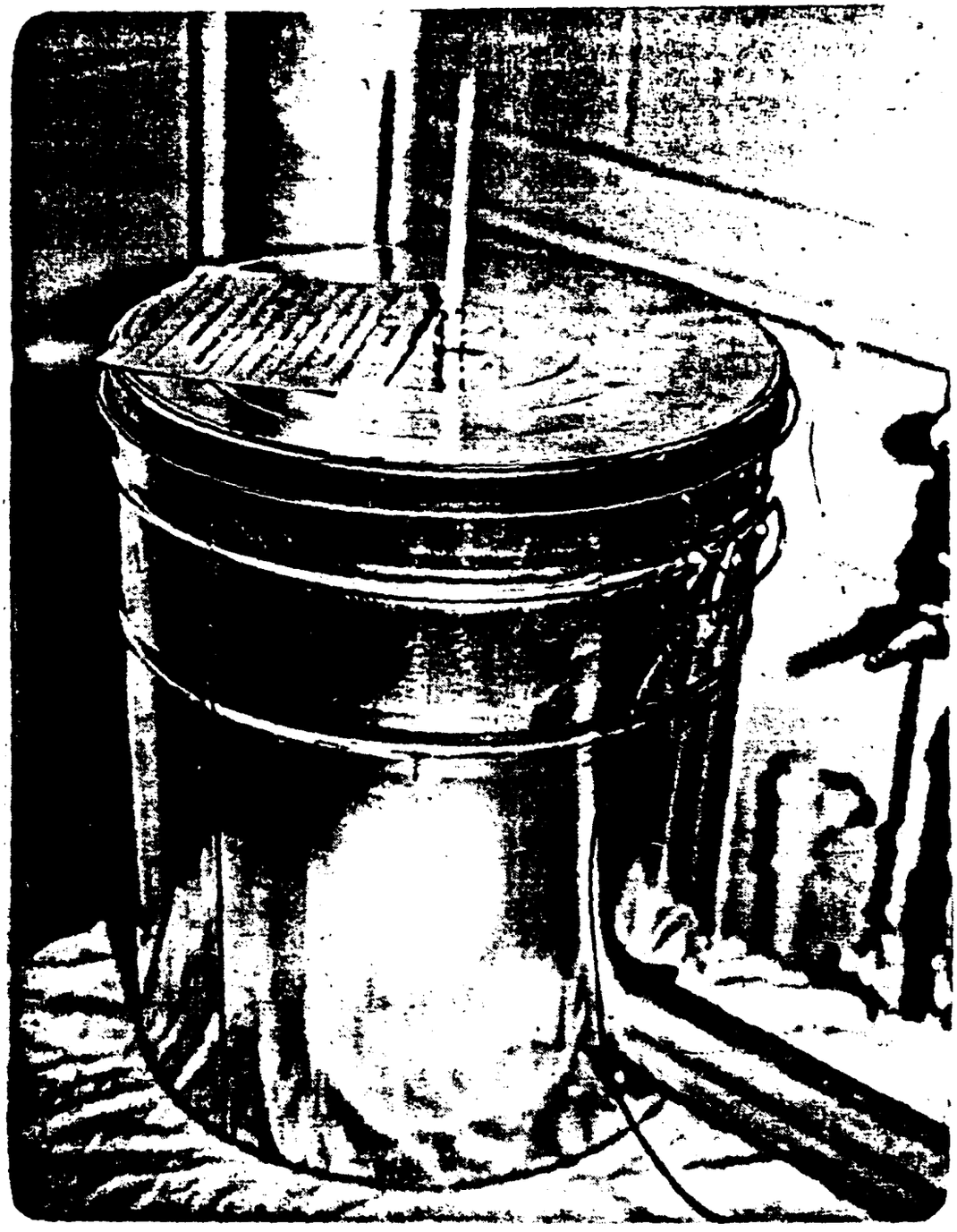

FIGURE A-5. EXPEDIENT OVEN

The procedure for the accelerated evaluation was based on the assumptions that:

(1) The rate of a chemical reaction doubled with every 18° F temperature increase.

(2) Room temperature was 70° F.

(3) The highest sustained temperature that the CF200 would be expected to withstand will be 140° F (in accordance with the procurement materials specifications.)

Based on these assumptions, calculations indicated that 288 hours at 140° F simulated 6 months at 70° F. The samples were placed in sealed test tubes to prevent the contaminants from boiling off before the test was completed.

Contaminants Used in the Evaluations

Three lists [1, 2, 3] of candidate contaminants were available which were quite extensive. Time and funds to evaluate all of them were not available, so the lists were pared down. This was done essentially by considering CF200 as a composite material and then selecting the contaminants which would attack either the nylon knit fabric or the rubber foam. The chemical resistance chart in reference 4 was used as an aid in the selection procedure.

Table A-1 shows the contaminants investigated in this evaluation of CF200. Each contaminant was considered by itself, even if it might be used to remove another contaminant. For example, smearing tar onto a sample and then scrubbing it with gasoline would have introduced too many variables for the scope of this study.

All of the contaminants were used in undiluted concentrations or, where applicable, in saturated solutions at room temperature. It was felt that any level of dilution would have been arbitrary, and that the undiluted solutions would yield conservative or "worse case" results.

Diving Scenario

The evaluation procedure described above is intended to simulate a diver getting a contaminant on his suit and to evaluate the rate at which the suit material can be expected to deteriorate. The following salvage dive scenario supported the selection of the contaminants.

It was assumed that the diver was going down to inxpect and work on either a ship's hull or an airplane or rocket fuselage. The diver was

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1. Commandant's Instruction M16465.12, U. S. Coast Guard, (October 1978).
2. Survey Study of Techniques to Prevent or Reduce Discharges of Hazardous Materials, Henderson, N. C. and Srinivasan, D., Battelle Memorial Institute Final Report to the U. S. Coast Guard, Contract DOT-CG-23223-A, Task XXI (August 15, 1975), p. 52-58.
3. Evaluation of the Hazard of Bulk Water Transportation of Industrial Chemicals - A Tentative Guide, PB 189 845, NAS, Washington, D. C. (1970).
4. Modern Plastics Encyclopedia, 1978-1979, McGraw-Hill, New York, NY, p. 558-560.

TABLE A-1 CONTAMINANTS USED IN EVALUATION OF CF 200

Assumed Threat	Contaminant	Concentration
1. Rubber	Gasoline	Undiluted
2. Rubber	JP-4 jet fuel	Undiluted
3. Rubber	Hydraulic oil, petroleum base, Mil-H-5606D	Undiluted
4. Rubber	Motor oil, 30W	Undiluted
	Inorganic Acids	
5. Nylon	Muriatic	Undiluted
6. Nylon	Sulfuric	Undiluted
	Organic Acids	
7. Nylon	Acetic Acid	Undiluted
8. Nylon	Formic Acid	Undiluted
9. Nylon	Toluene	Undiluted
10. Nylon	Phenol	Saturated in ethyl alcohol
	Amines	
11. Nylon	Diethylenetriamine	Undiluted
12. Nylon	Morpholine	Undiluted
	Bases	
13. Nylon	Calcium Hypochlorite	Saturated in water at room temperature
14. Nylon	Potassium Hydroxide	Saturated in water at room temperature
	Glycols	
15. Nylon	Ethylene Glycol	Undiluted
	Halogens	
16. Nylon	Methylene Chloride	Undiluted
	Ketones	
17. Nylon	Methyl Ethyl Ketone	Undiluted

TABLE A-1 (Continued)

Assumed Threat	Contaminant	Concentration
	Silicones	
18. Nylon	Silicone Oil, Dow Corning 550	Undiluted
19. Nylon	Ethyl Silicate	Undiluted
	Miscellaneous	
20. Nylon	Hydraulic Fluid, Phosphate Ester, Skydrol 500B	Undiluted
21. Nylon	Tide Detergent	Saturated in water at room temperature

Two other contaminants--brake fluid and crude oil--were eliminated due to time and fund limitations.

assumed to suit up either in a ship's cabin or on deck. In walking to either a ladder off the ship's side or to a diver's stage, the diver's suit might contact oil decks (grease, diesel fuel, petroleum-base hydraulic fluid, or lubricating oil), machinery or tools. Puddles of battery acid might also be present.

When the diver enters the water he might come into contact with non-water-soluable debris floating on the surface. This might include balls of crude oil or Bunker C and engine bilge. As the diver descends he might pass through plumes of water-soluable contaminants but these would likely be quite diluted by the ocean currents.

When the diver reaches his destination, assumed to be the bottom, he might come into contact with contaminants which are dense enough to have sunk or sticky enough to have remained on or in objects that have sunk. Hazardous free-flowing chemicals may have already dispersed by the time the diver arrives, although some could still be leaking from some nearby source. Possible contaminants include petroleum products such as Diesel Fuel, Marine (DFM), Navy Special Fuel Oil (NSFO), JP-4, or JP-5. An airplane or missle might be leaking phosphate ester hydraulic fluid or rocket fuels.

After an assumed stay at the bottom of two hours the diver was assumed to surface, again passing through floating debris, and arrives on the deck of the ship. After he unsuited, he was assumed to wash the dry suit inside and out and to inspect it for stains and cuts. It was then assumed that his suit would be stored in a locker at room temperature for six months.

APPENDIX B

CF200 EVALUATION DATA MATRIX

APPENDIX B

CF200 EVALUATION DATA MATRIX

This appendix contains the data from the CF200 evaluation. The contaminants, evaluation time intervals, and strength values are shown in a tabular form.

Table B-1 contains a summary of the results of the evaluation in a matrix format.

Table B-2 contains the data from the evaluation and the averaged values, form which Table B-1 was prepared.

Contaminant	Tensile Strength, Lbs				Peel Strength, Lbs at 5 inches/minute							
	0 Aging	1 Min	2 Hrs	12 Days	0 Aging	Failure Type	1 Min	Failure Type	2 Hrs	Failure Type	12 Days	Failure Type
Assumed Rubber Threats												
Gasoline	119	111	111	118	16	A	3.3	A	3.5	A	2.0	A
JP 4	128	130	112	121	18	A	8	A	7	A	4.5	A,D
Hydraulic oil Mil-H-5606D	128	117	127	128	16	A	14	A	12	A	8	A,D
Motor oil, 30W	126	139	133	137	17	A	17.3	A	18	A	13.5	A
Assumed Nylon Threats												
Muriatic acid	125	28	27	--	16	A	7.8	C	8.3	C	--	--
Sulfuric acid	126	27	21	--	16	A	8.8	C	0.8	C	--	--
Acetic acid	125	98	92	81	17	A	12.5	A,B	6.6	B	4.3	B
Formic acid (88% conc.)	128	27.6	26	--	16	A	7	C	1.5	C	--	--
Toluene	122	128	118	103	17	A	1.6	A,D	1.0	A,D	0.7	A,D
Phenol (sat in ethanol)	126	30	25	--	16	A	10.8	A,C	12	C	--	--
Diethylenetriamine	126	112	111	118	17	A	13	A,B	9.3	B	0.8	B
Morpholine	125	119	105	92	16	A	12	A,B	9	A	0.3	B
Calcium hypochlorite/ Water 20/80	123	121	103	112	17	A	5.7	A	5.8	A	4.0	B
Potassium Hydroxide/ Water 50/50	129	93	91	70	16	A	13.5	A	15	A	0.8	B
Ethylene glycol	127	123	134	137	17	A	16	A	15	A	2	B
Methylene chloride	121	113	109	93	13	A	8	A	1.3	A,D	1.2	A,D
MEK	126	130	129	97	17	A	8	A,D	3.8	A,D	1.7	A,D
Ethyl silicate	126	122	125	115	17	A	13	A	11	A	7	A
Silicone oil Dow Corning 550)	128	125	138	118	17	A	19	A	16	A	10	A
Skydrol 500B	132	116	118	107	18	A	9.5	A	5.5	A	1.6	A,D
Tide/water	124	99	106	117	17	A	11	A,B	14	A	1.7	B

TABLE B-1. RESULTS OF CF200 EVALUATION

Failure Type:

A - Rubber to Rubber
B - Adhesive to Fabric
C - Fabric Tears
D - Much Swelling
--Not tested

Contaminant	Immersion Times	Tensile Breaking Strength, Lb				Peel Strength, Lb, at 5 in/Min			
		Trial 1	Trial 2	Trial 3	Avg	Trial 1	Trial 2	Trial 3	Avg
Gasoline	Baseline	116	118	122	119	16	15	16	16
	1 minute	110	112	110	111	3.5	3.4	3.0	3.3
	2 hours	114	106	114	111	3.5	3.6	3.3	3.5
	12 days	115	128	110	118	2.5	1.8	1.7	2
JP 4	Baseline	130	130	125	128	18	18.5	17	18
	1 minute	122	145	123	130	6	7	12	8
	2 hours	108	117	110	112	5.5	7	8	7
	12 days	122	126	116	121	4.5	4.4	4.5	4.5
Hydraulic Fluid Mil H 5606D Petroleum Based	Baseline	135	122	126	128	16	16	16.5	16
	1 minute	122	112	118	117	17	15	11	14
	2 hours	136	124	122	127	8.5	13	16	12
	12 days	132	124	128	128	7.5	8	8.5	8
Motor Oil, 30W	Baseline	130	125	122	126	17	18	17	17
	1 minute	150	135	133	139	17.5	17	17.5	17.3
	2 hours	148	125	127	133	17	18	18	18
	12 days	132	140	138	137	13.5	13	14	13.5
Muratic Acid	Baseline	128	123	124	125	17	16	16	16
	1 minute	27	28.5	29	28	9.3	7	7	7.8
	2 hours	30	25	25	27	9.5	8.5	7	8.3
Sulfuric Acid	Baseline	125	122	130	126	16	15	17	16
	1 minute	28	26	27	27	8.8	10	7.5	8.8
	2 hours	18	20.5	23.5	21	0.8	1	0.5	0.8
Acetic Acid	Baseline	128	122	125	125	17	18	16	17
	1 minute	100	94	100	98	14.5	15	8	12.5
	2 hours	92	94	90	92	15.2	3.5	1	6.6
	12 days	80	80	84	81	6	5	2	4.3
Formic Acid	Baseline	130	125	128	128	16	16	16	16
	1 minute	27.5	27	28	27.5	6.8	7.6	6.7	7
	2 hours	26	27	25	26	1.5	1.3	1.6	1.5
Toluene	Baseline	120	135	112	122	17	18	16	17
	1 minute	115	138	130	128	1.7	1.0	2.0	1.6
	2 hours	124	108	121	118	1.1	0.8	1.1	1
	12 days	102	104	Slip	103	0.6	0.7	0.7	0.7

TABLE B-2. EVALUATION DATA

Contaminant	Immersion Times	Tensile Breaking Strength, Lb				Peel Strength, Lb, at 5 in/Min			
		Trial 1	Trial 2	Trial 3	Avg	Trial 1	Trial 2	Trial 3	Avg
Phenol	Baseline	130	122	126	126	16	16	16	16
	1 minute	30	30	29	30	9	13.5	10	10.8
	2 hours	25	25	25	25	13.5	10	12	12
Diethylene-triamine	Baseline	125	130	124	126	17	16	18	17
	1 minute	112	104	120	112	12	10.5	17	13
	2 hours	108	120	105	111	16	5	7	9.3
	12 days	125	120	110	118	08	1.0	0.7	0.8
Morpholine	Baseline	122	129	124	125	15.5	16	17	16
	1 minute	115	123	120	119	5	16	15	12
	2 hours	110	100	104	105	9	9	9	9
	12 days	94	90	--	92	0.3	0.2	0.3	0.3
Calcium Hypochlorite	Baseline	125	122	122	123	16	17	18	17
	1 minute	122	121	120	121	14	15	18	15.7
	2 hours	98	110	100	103	15	16.5	16	15.8
	12 days	107	118	110	112	4	3	5.4	4
Potassium Hydroxide	Baseline	128	134	125	129	16	16	16	16
	1 minute	95	90	90	93	14	13.5	13	13.5
	2 hours	90	92	90	91	16	14	15	15
	12 days	42	85	82	70	0.7	0.7	1.0	0.8
Ethylene Glycol	Baseline	128	122	130	127	17	18	16	17
	1 minute	126	122	120	123	16	16	16.5	16
	2 hours	148	130	125	134	15.5	15	15	15
	12 days	144	138	130	137	1.7	2.5	2	2
Methylene Chloride	Baseline	120	122	120	121	16	13	10.5	13
	1 minute	120	115	105	113	8	7	9.5	8
	2 hours	97	117	114	109	1.2	1.3	1.3	1.3
	12 days	--	96	90	93	1.0	1.2	1.3	1.2
Methyl Ethyl Ketone	Baseline	130	125	122	126	17	18	17	17
	1 minute	130	125	134	130	15	4	5	8
	2 hours	128	120	139	129	3.2	3.7	4.5	3.8
	12 days	105	96	90	97	1.5	1.5	2.0	1.7
Silicone Oil DC 550	Baseline	125	130	128	128	18	17	17	17
	1 minute	124	126	126	125	18	20	19	19
	2 hours	130	155	130	138	17	16	15	16
	12 days	128	120	106	118	9 a	10	10	10

TABLE B-2. CONTINUED.

APPENDIX C

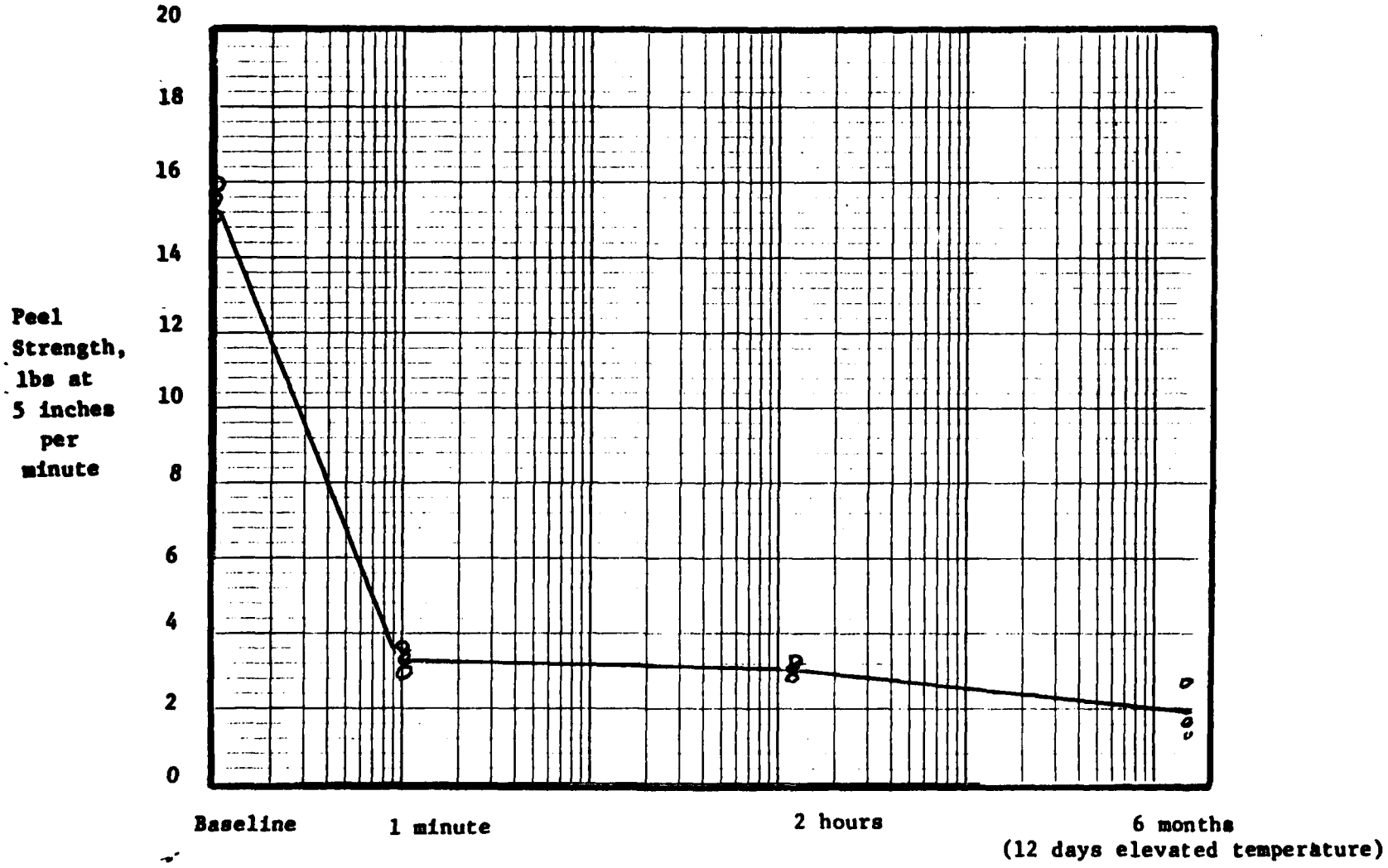
PLOTS OF CF200 EVALUATION DATA - TENSILE STRENGTH AND PEEL STRENGTH

APPENDIX C

PLOTS OF CF200 EVALUATION DATA - TENSILE STRENGTH AND PEEL STRENGTH

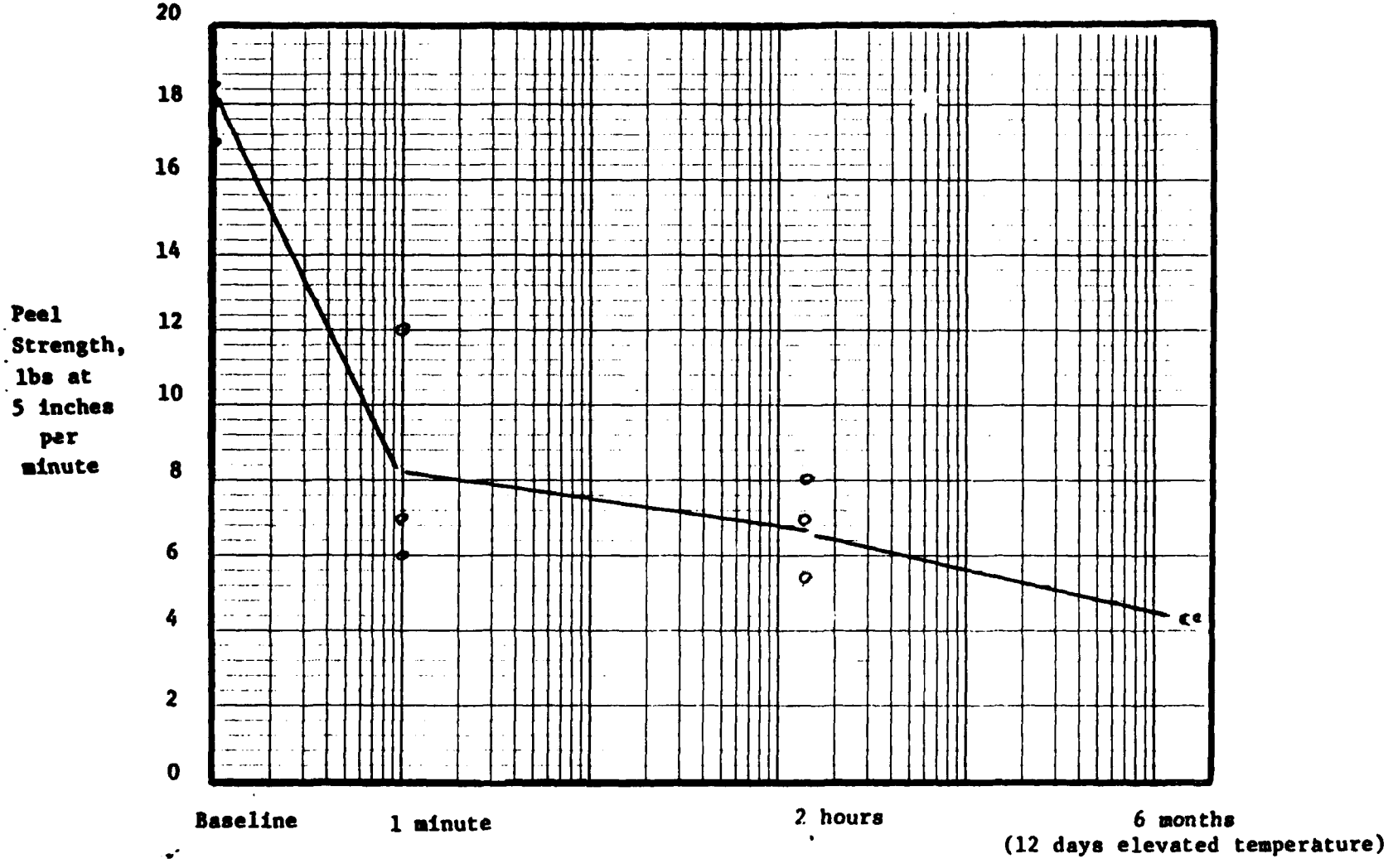
The tensile strength and peel strength data of the CF200 material are presented in this section as follows:

Unseamed CF200 Peel Strength Plots	Figures C-1 through C-21
Unseamed CF200 Tensile Strength Plots	Figures C-22 and C-23
Seamed CF200 Peel Strength Plot	Figures C-24
Seamed CF200 Tensile Strength Plot	Figure C-25



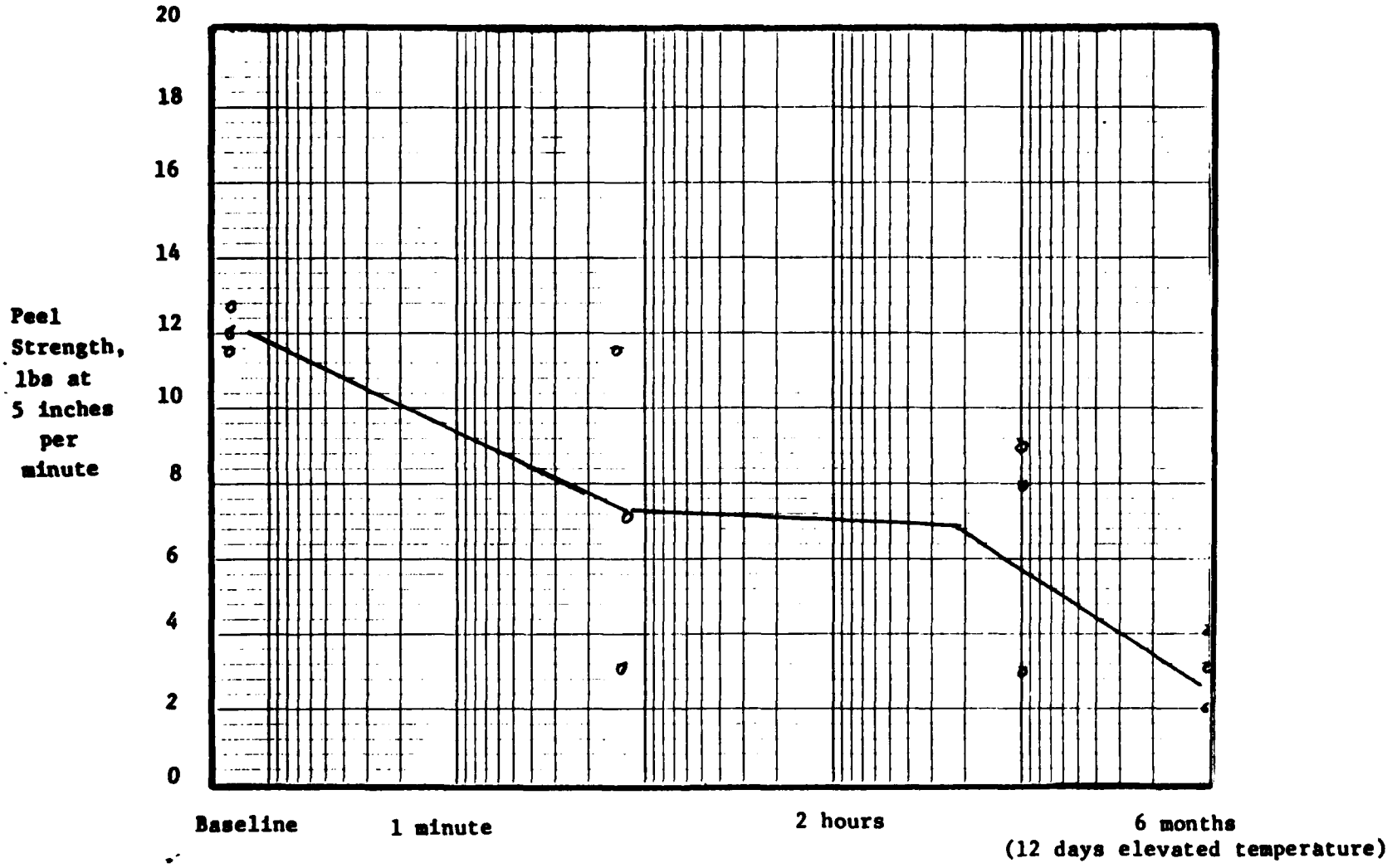
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Gasoline

Figure C-1.



NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: JP-4

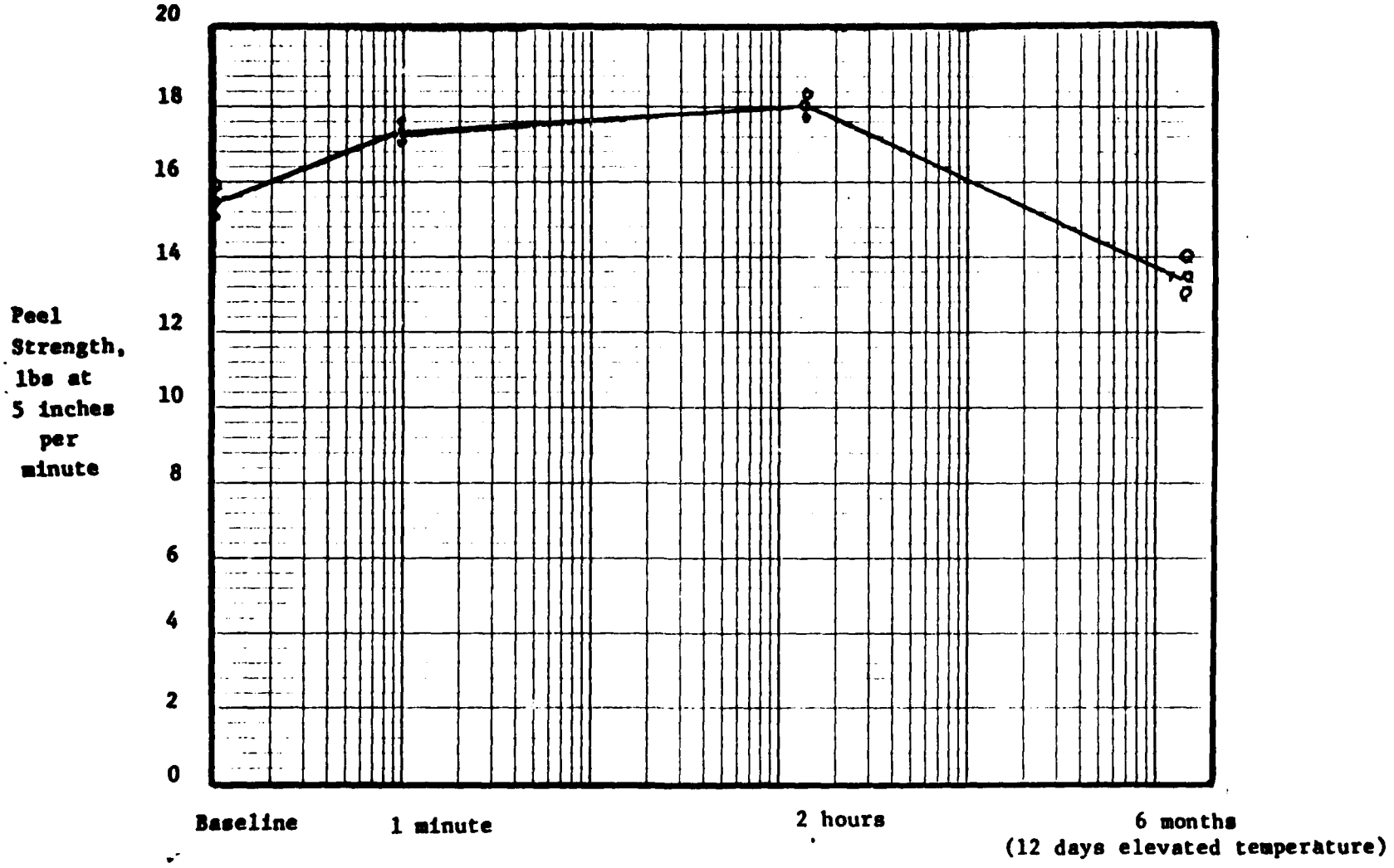
Figure C-2.



NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME

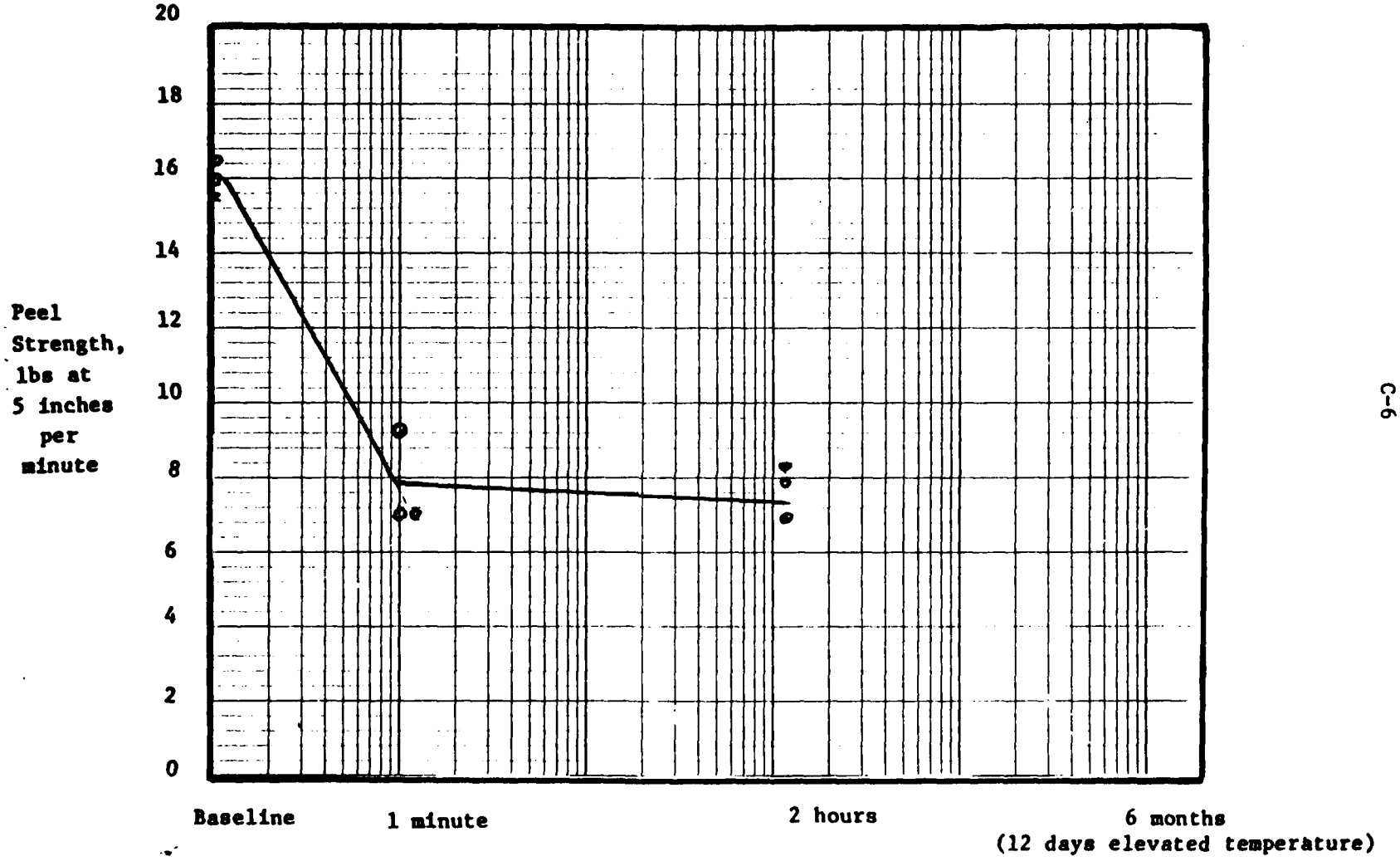
Contaminant: Hydraulic oil, Mil-H-5606D

Figure C-3.



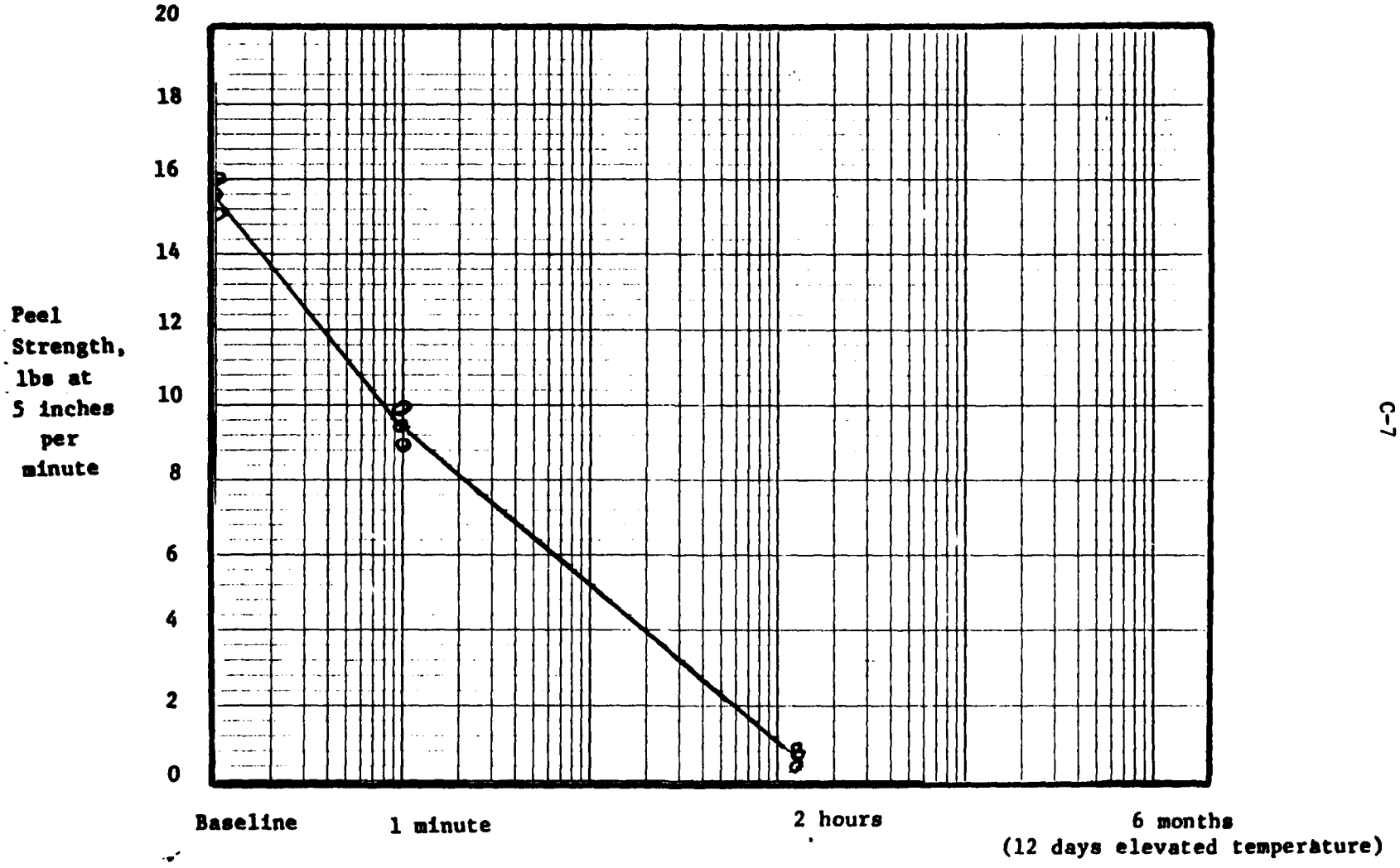
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Motor oil, 30W

Figure C-4.



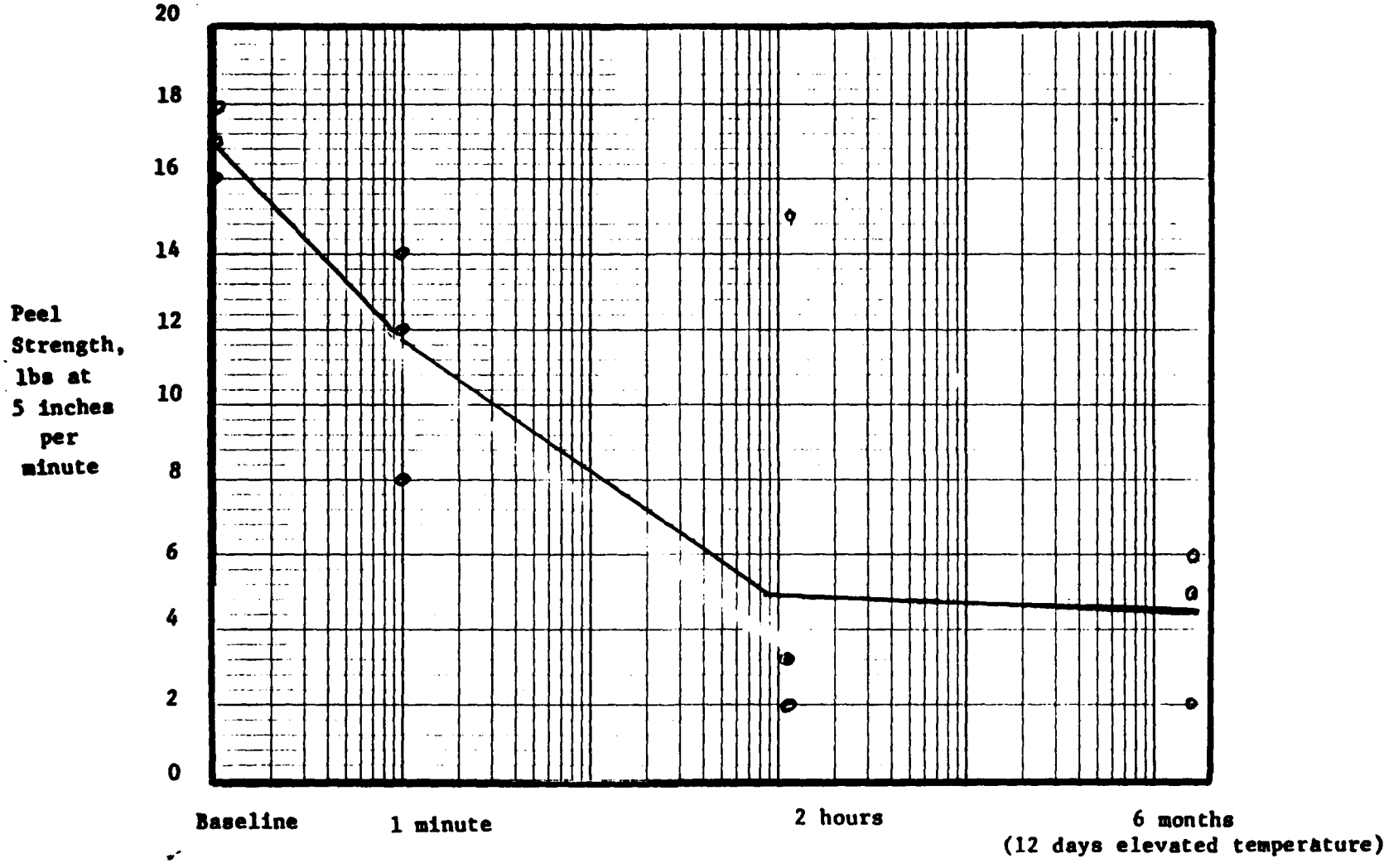
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Muratic acid

Figure C-5.



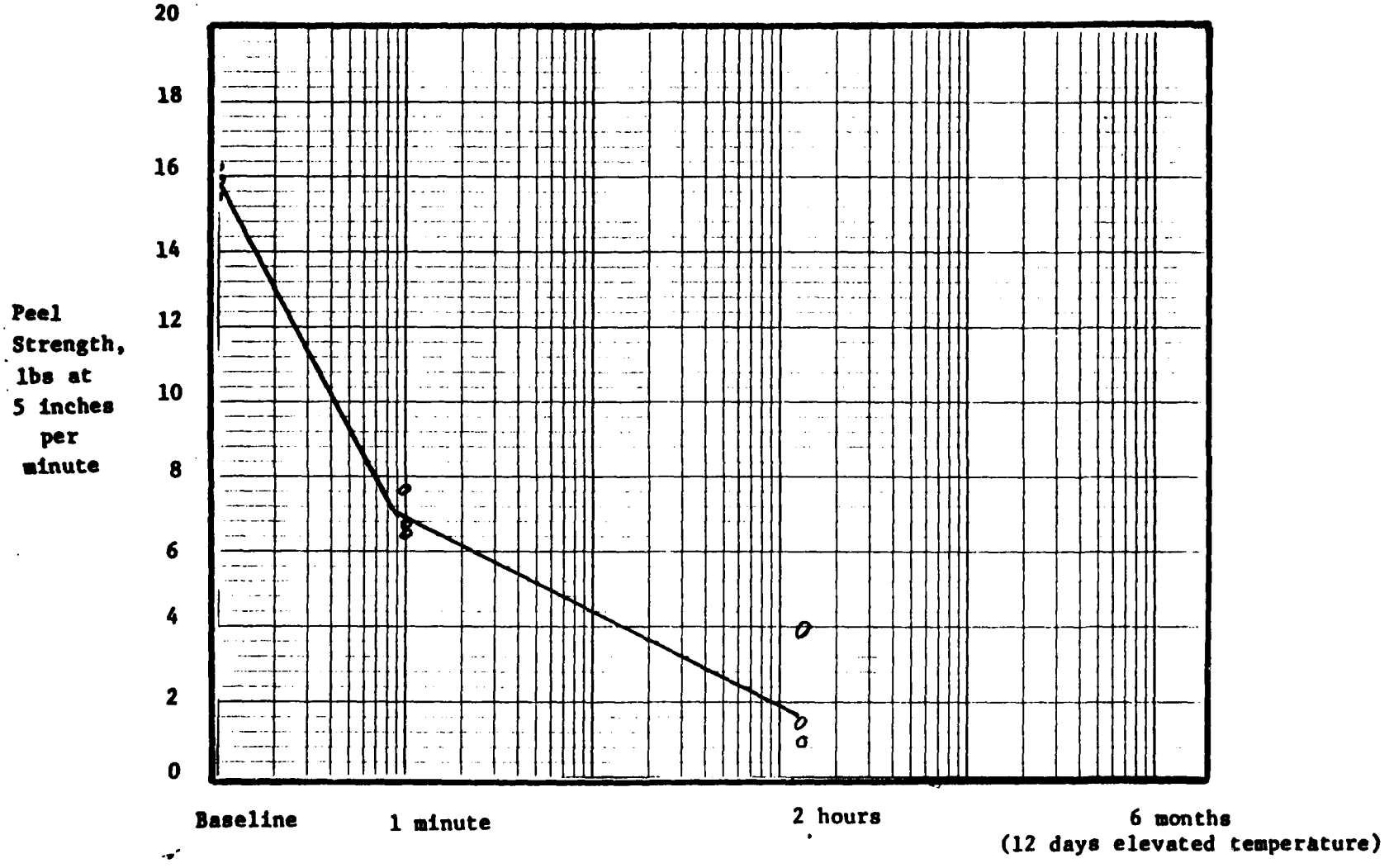
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Sulfuric acid

Figure C-6



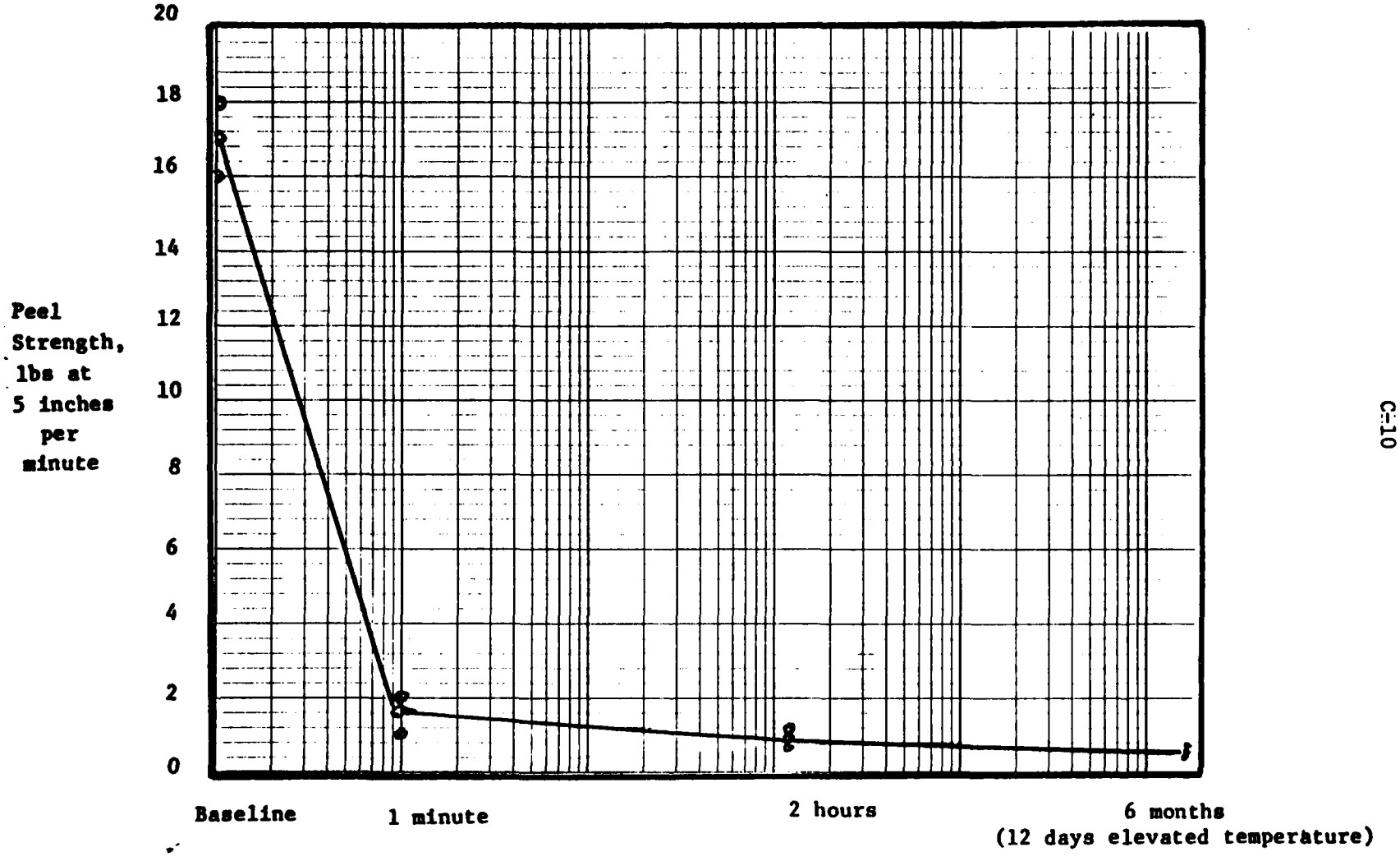
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Acetic acid

Figure C-7.



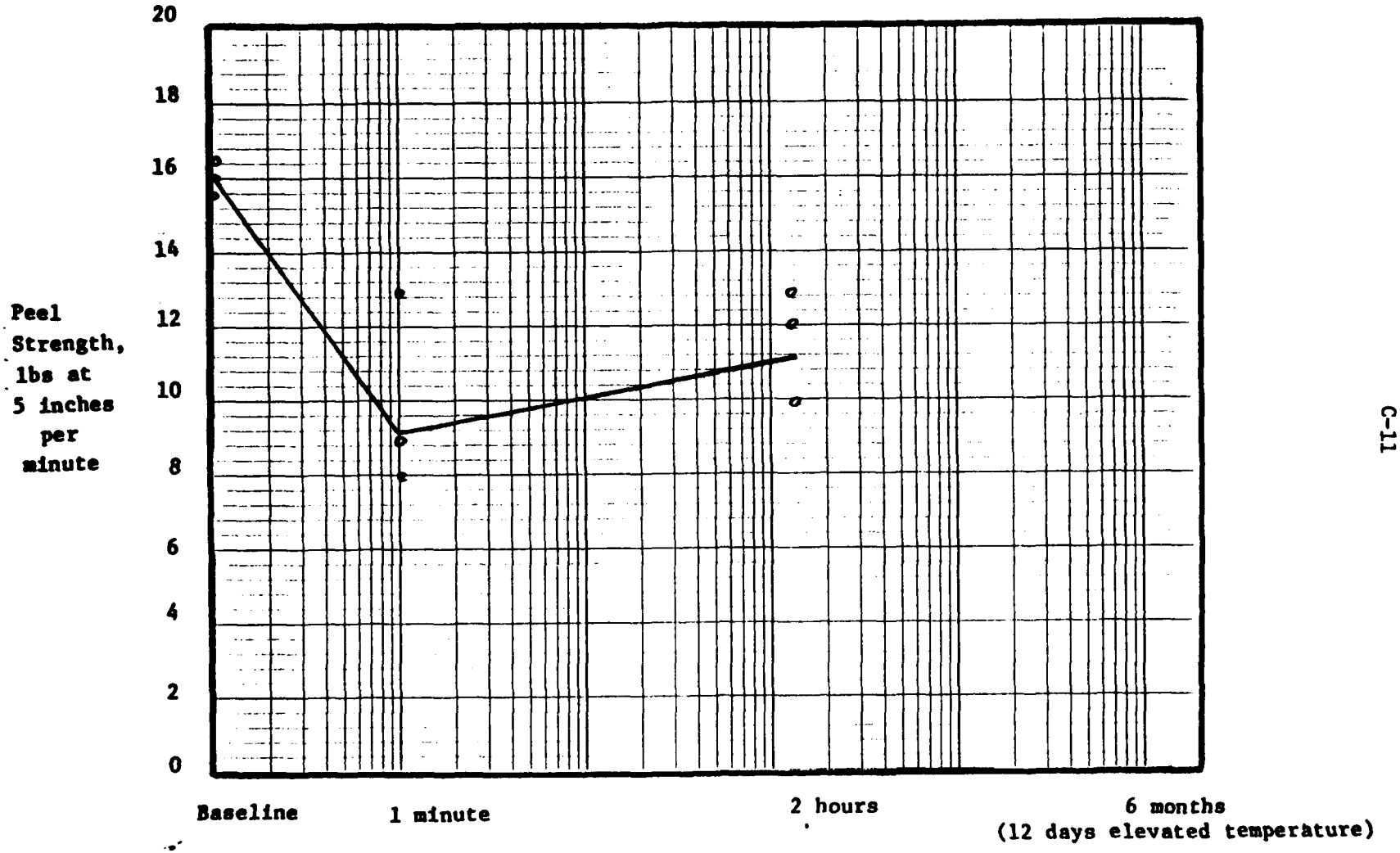
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Formic acid (88% conc.)

Figure C-8.



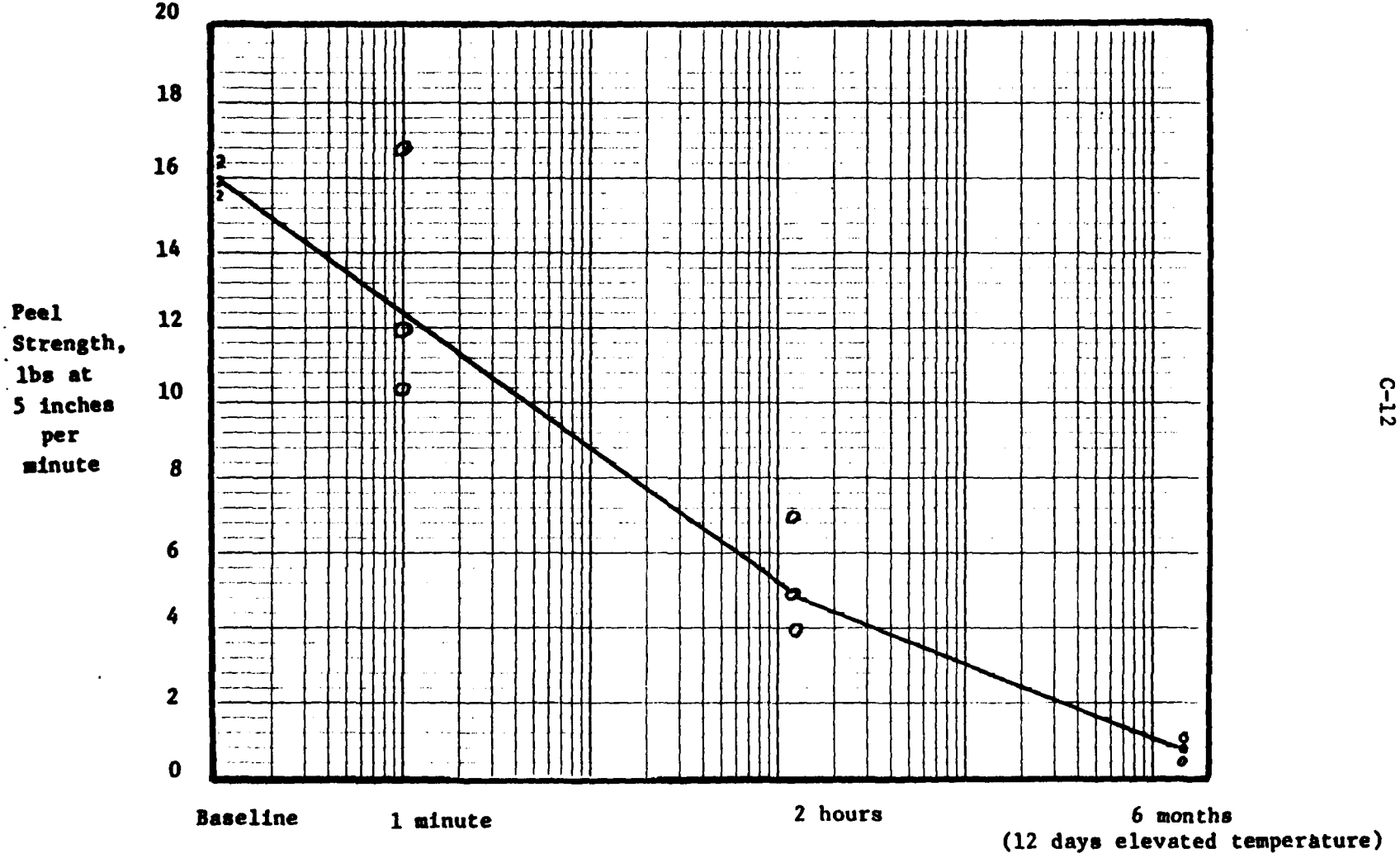
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Toluene

Figure C-9.



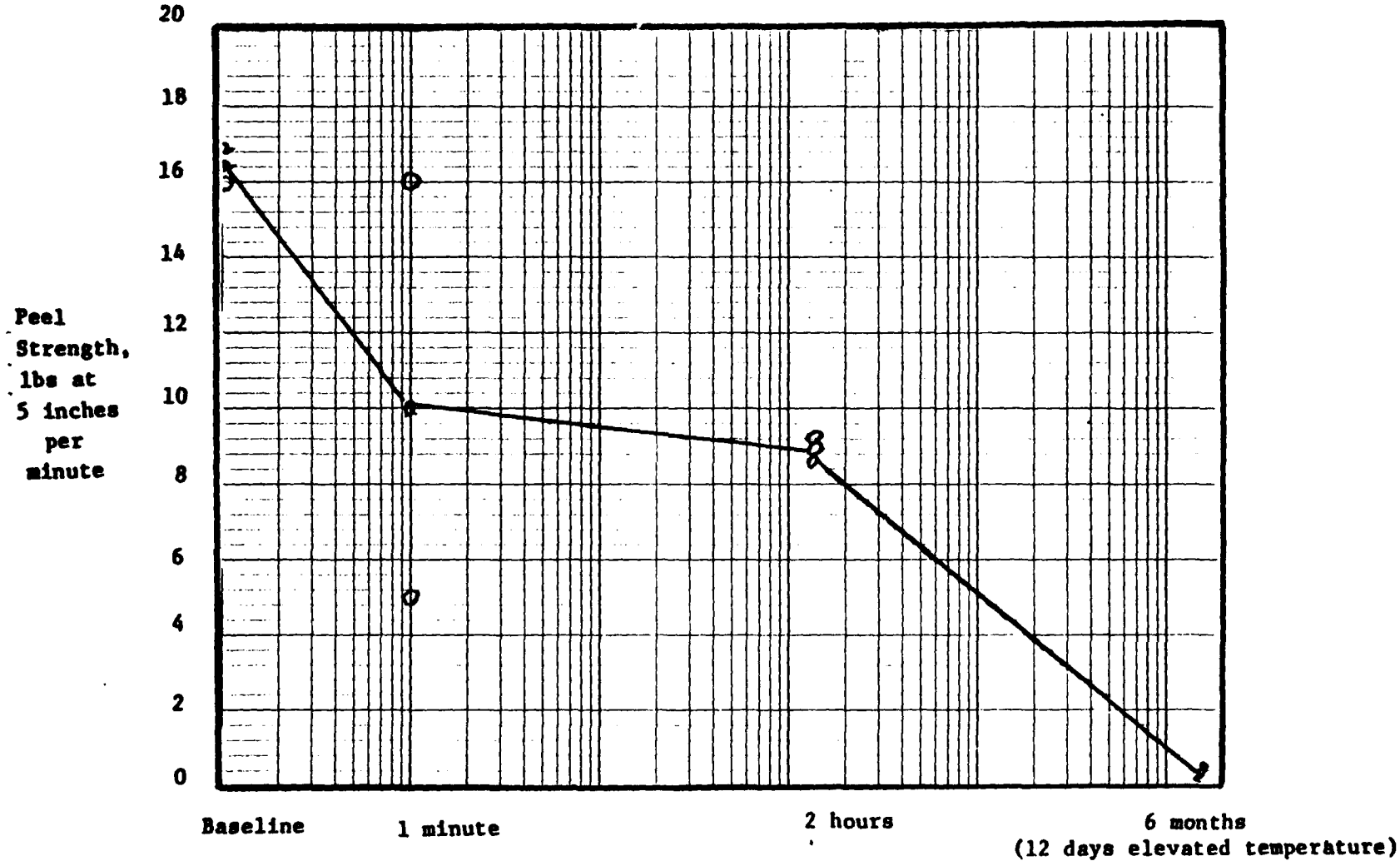
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Phenol (saturated in ethanol)

Figure C-10.



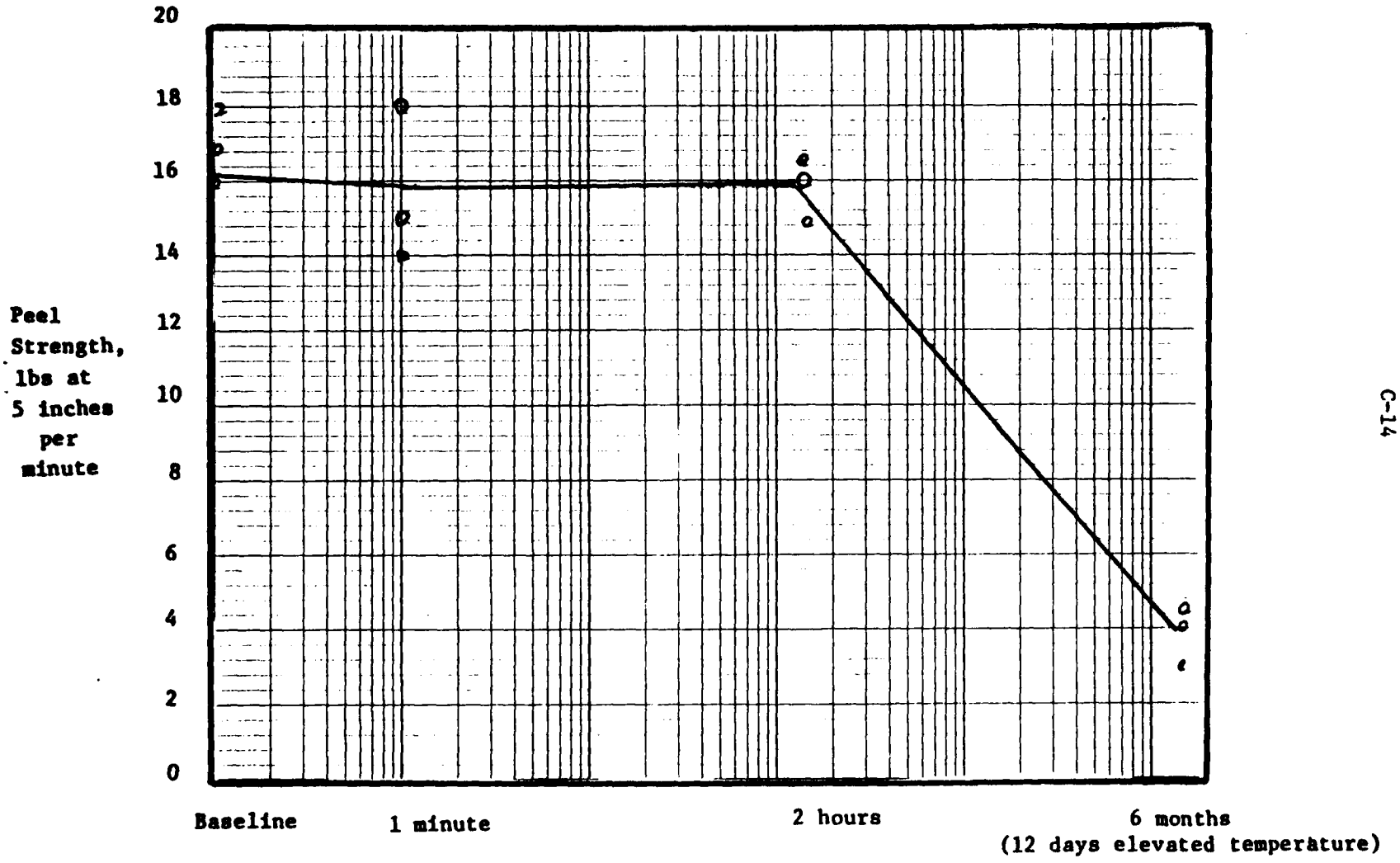
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Diethylenetriamine

Figure C-11.



NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Morpholine

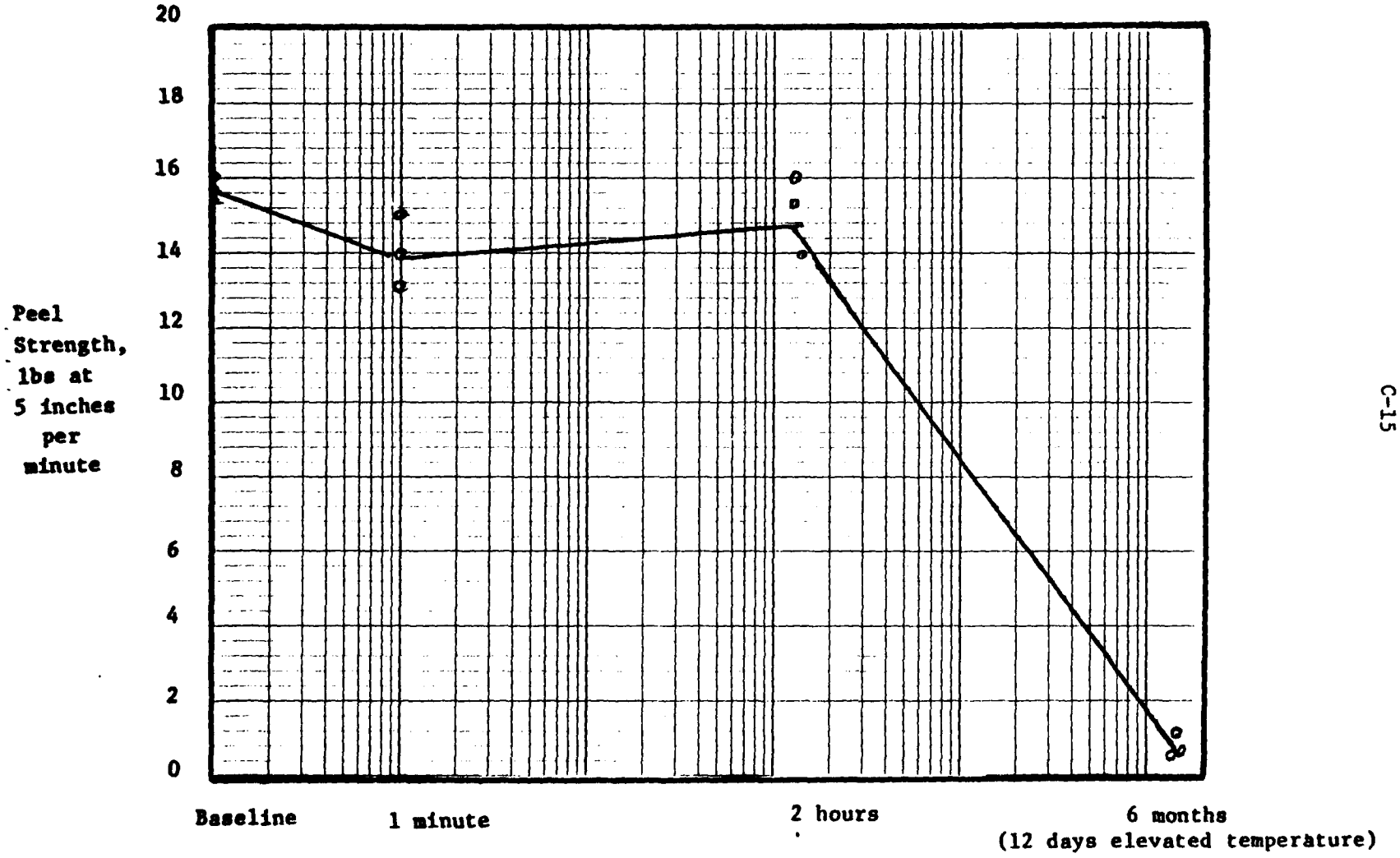
Figure C-12.



NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME

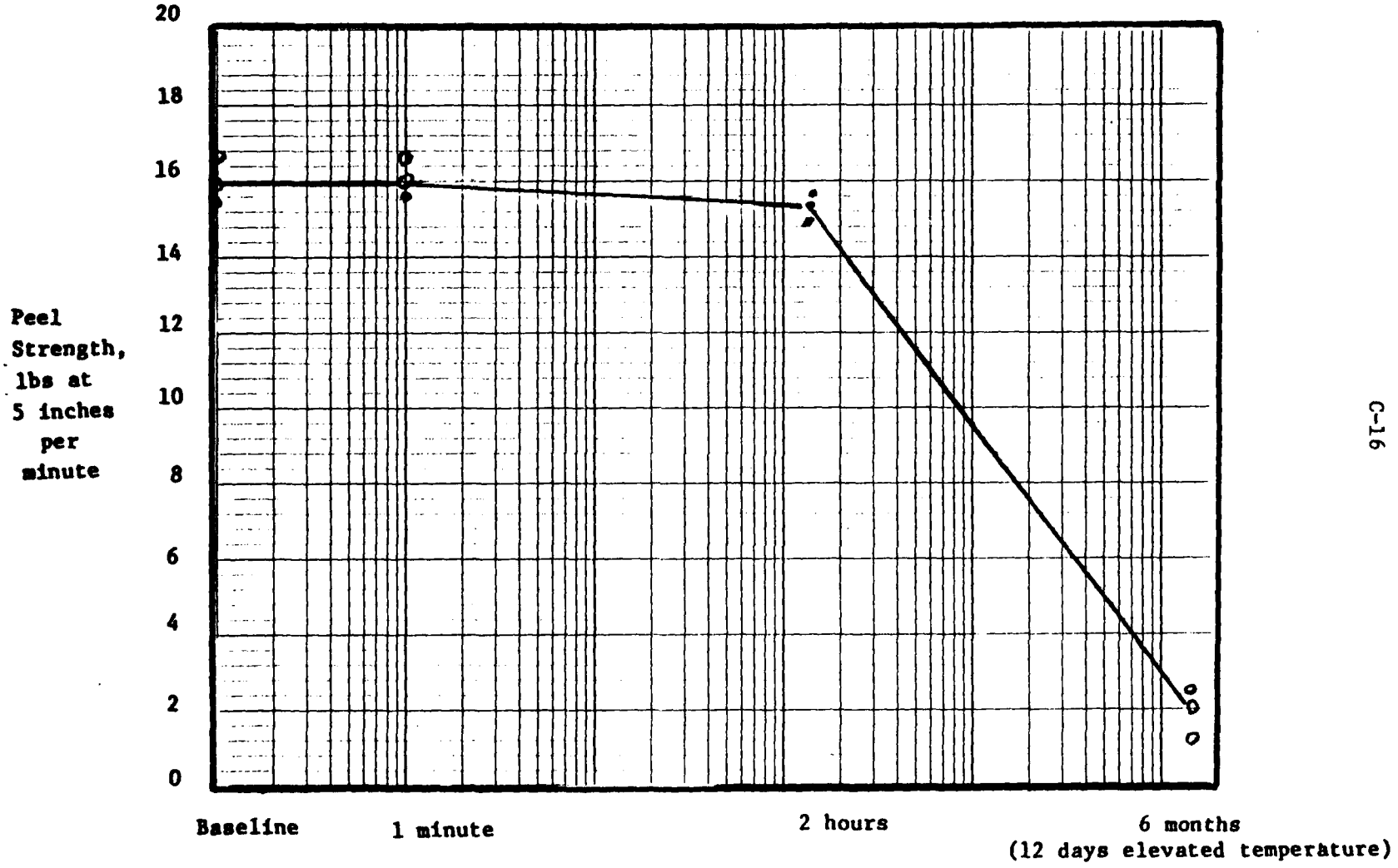
Contaminant: Calcium hypochlorite/
Water 20/80

Figure C-13.



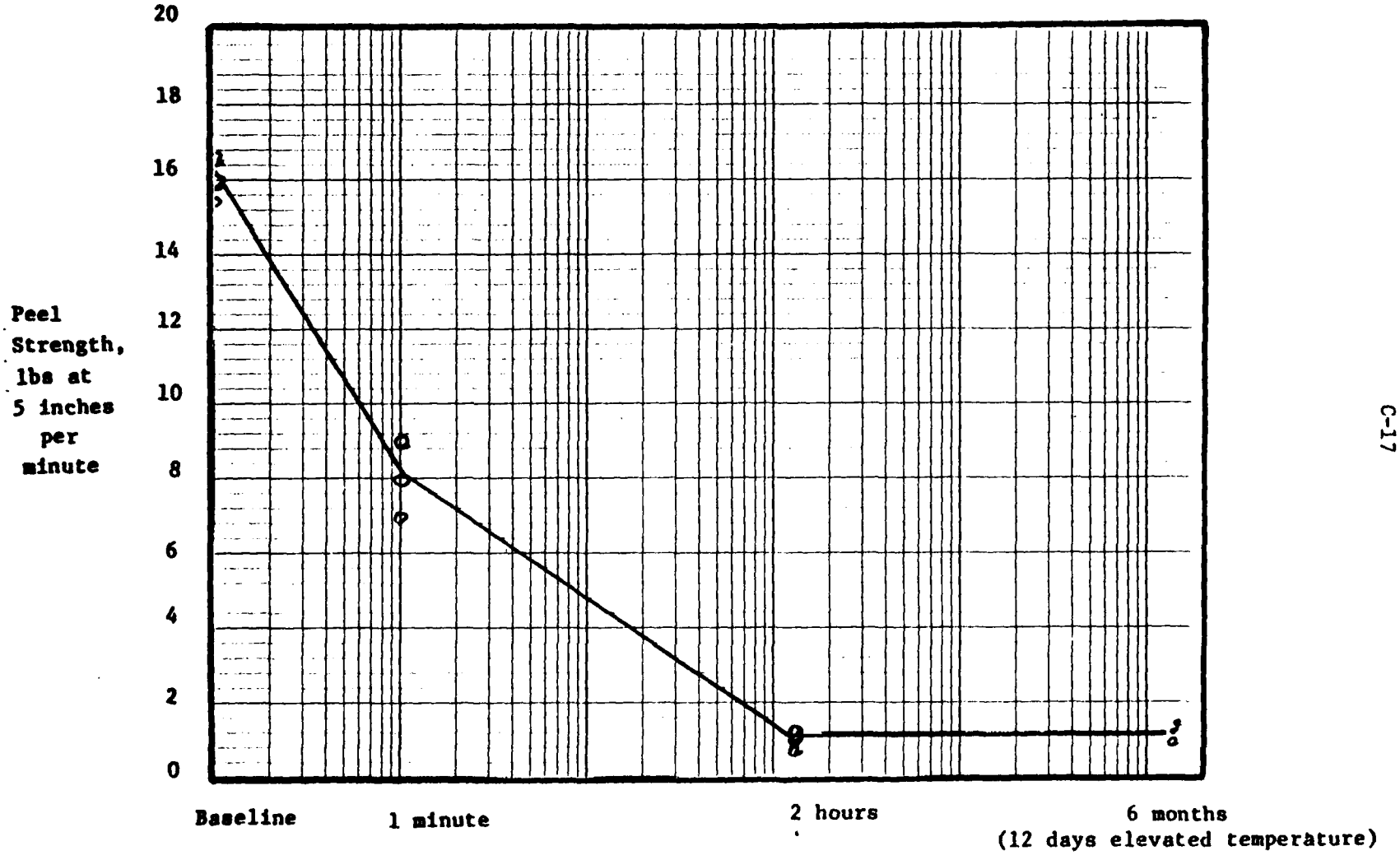
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Potassium Hydroxide/
Water 50/50

Figure C-14.



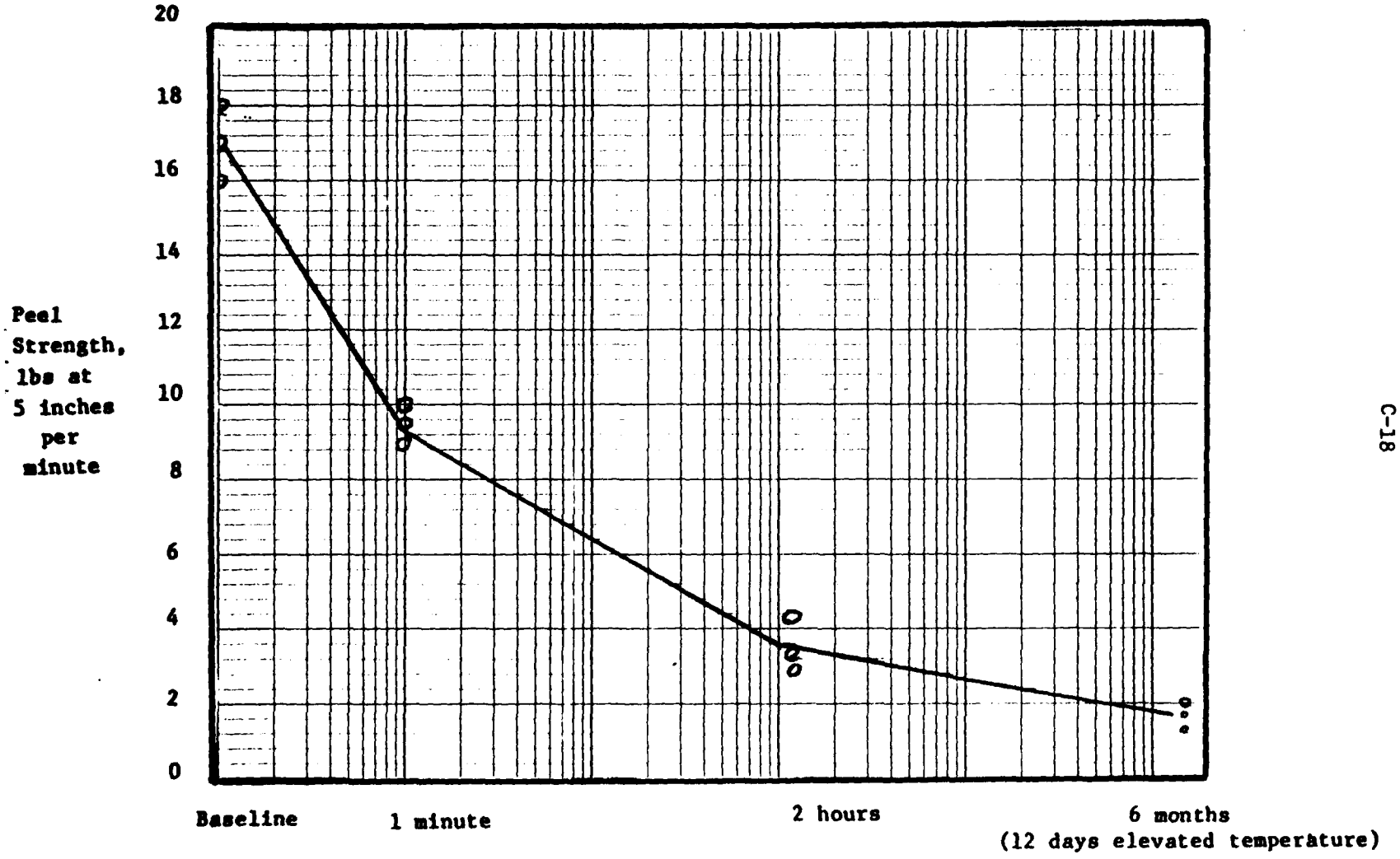
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Ethylene glycol

Figure C-15.



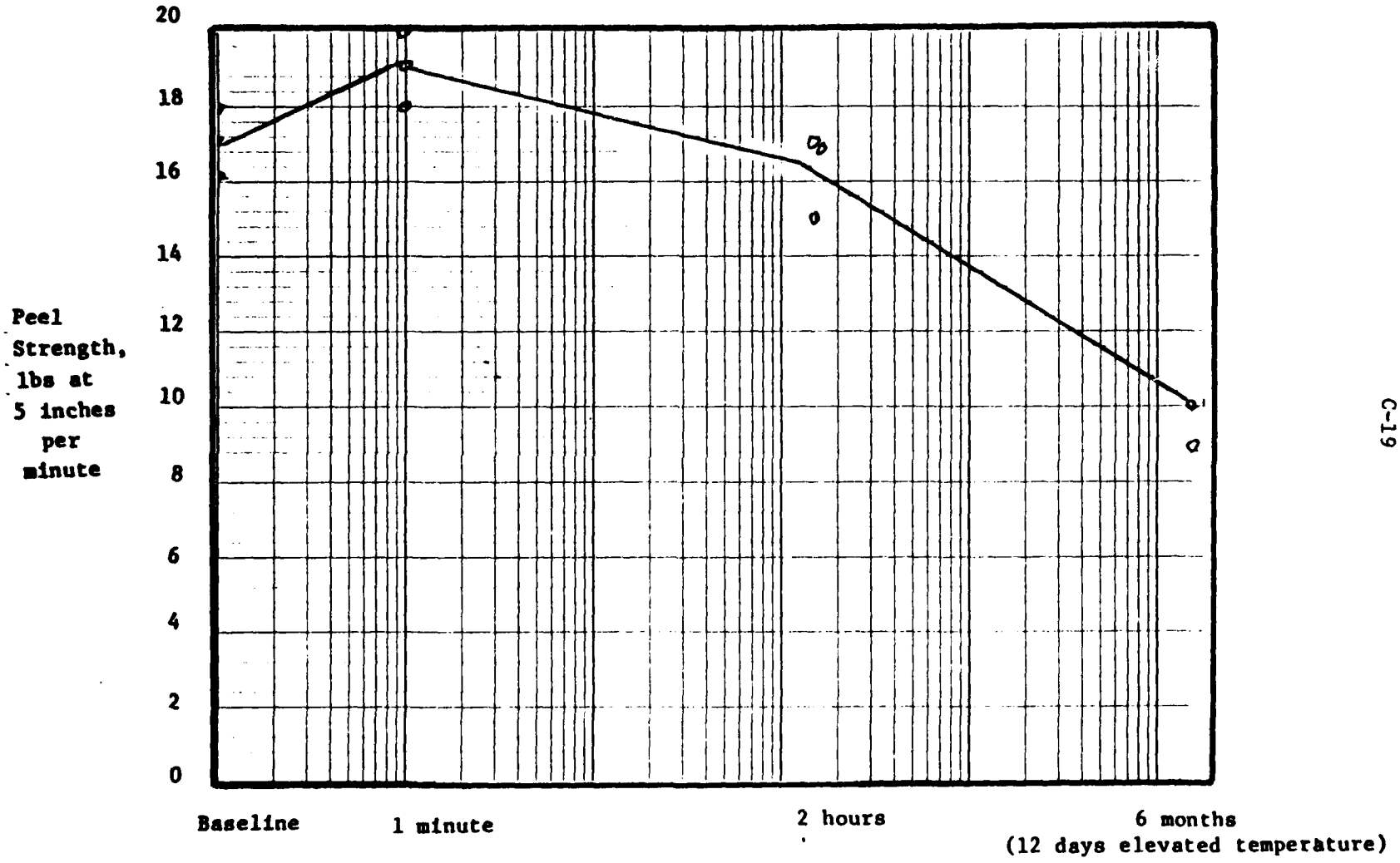
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Methylene chloride

Figure C-16.



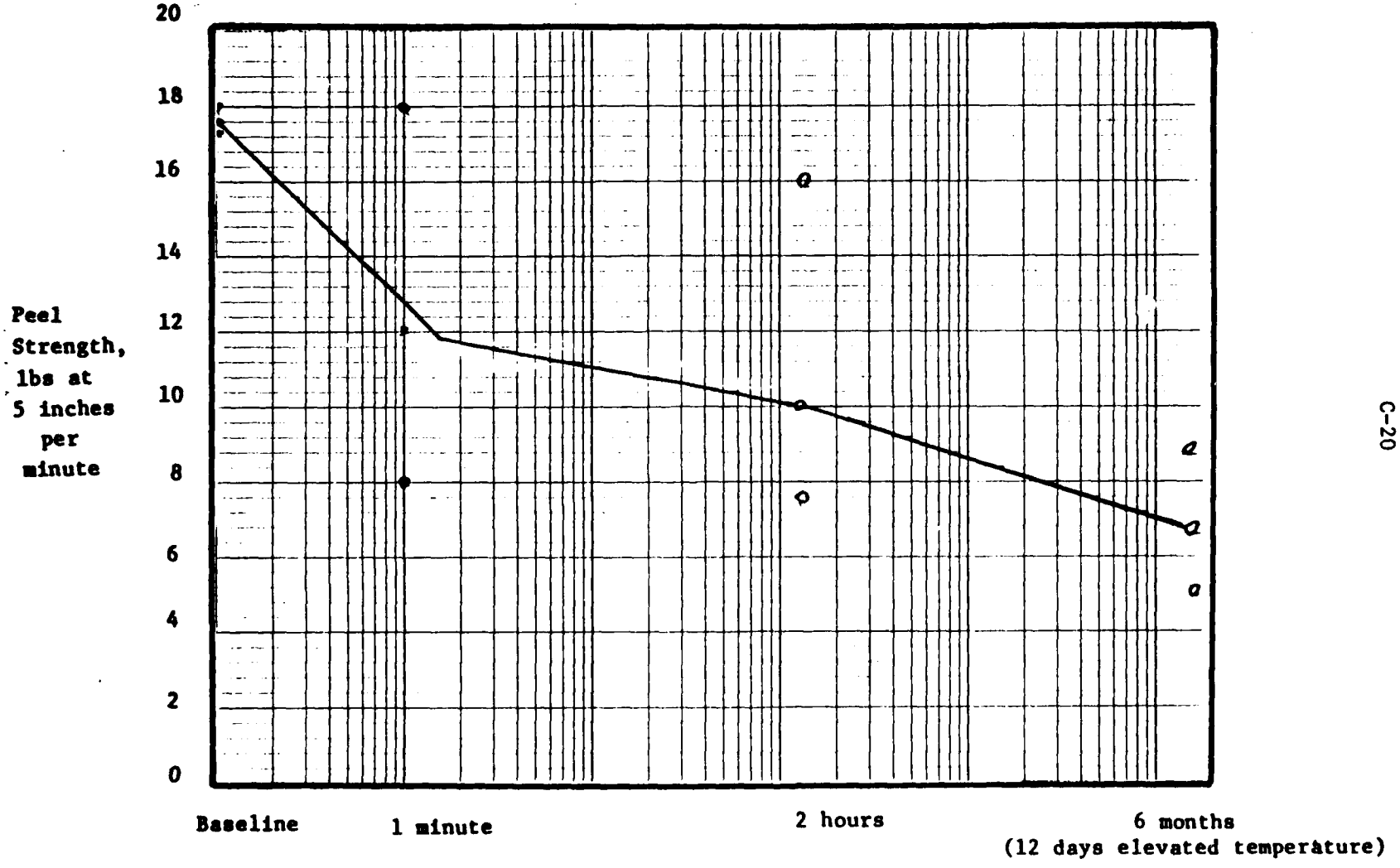
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: MEK

Figure C-17.



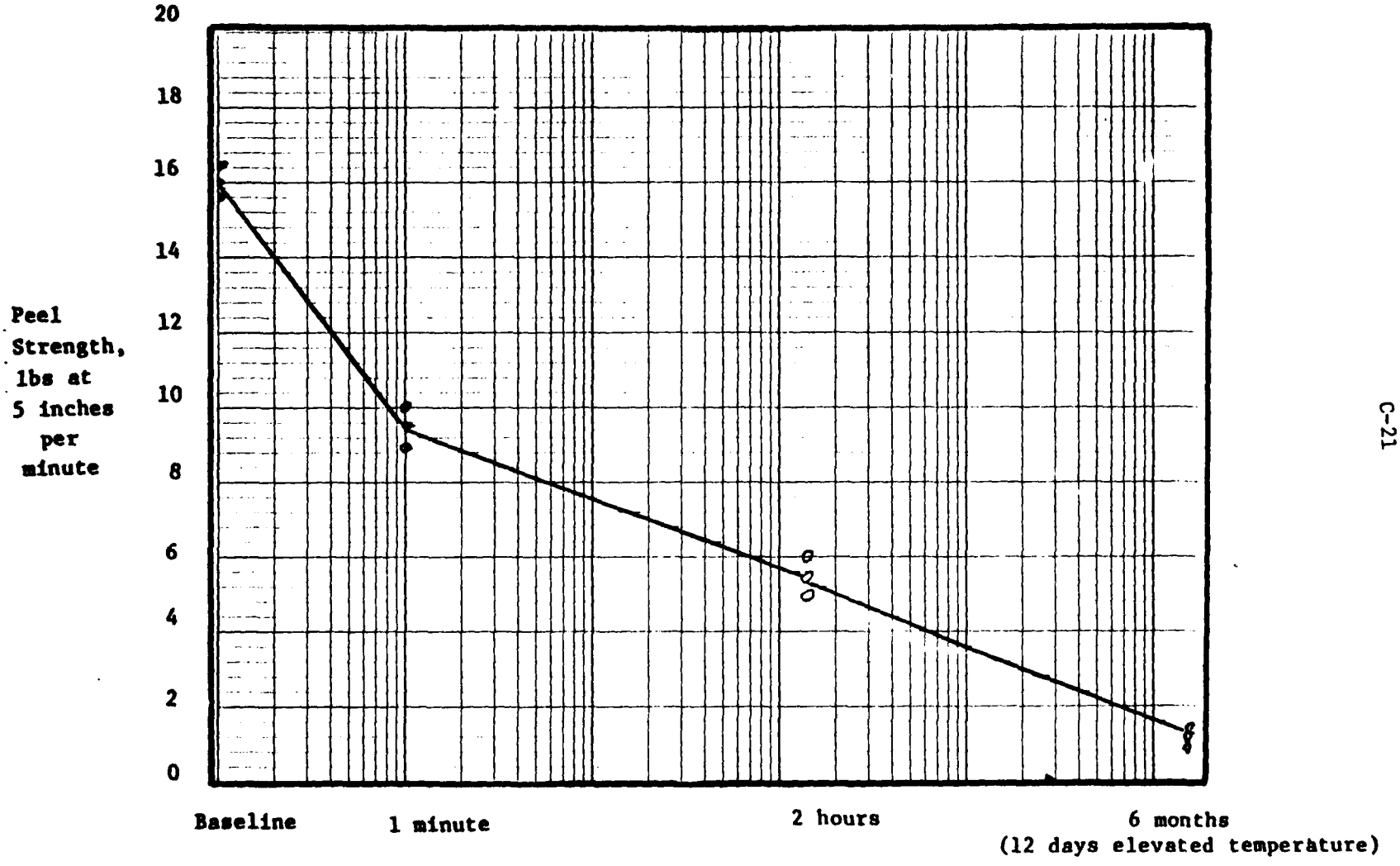
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Silicone oil
(Dow Corning 550)

Figure C-18.



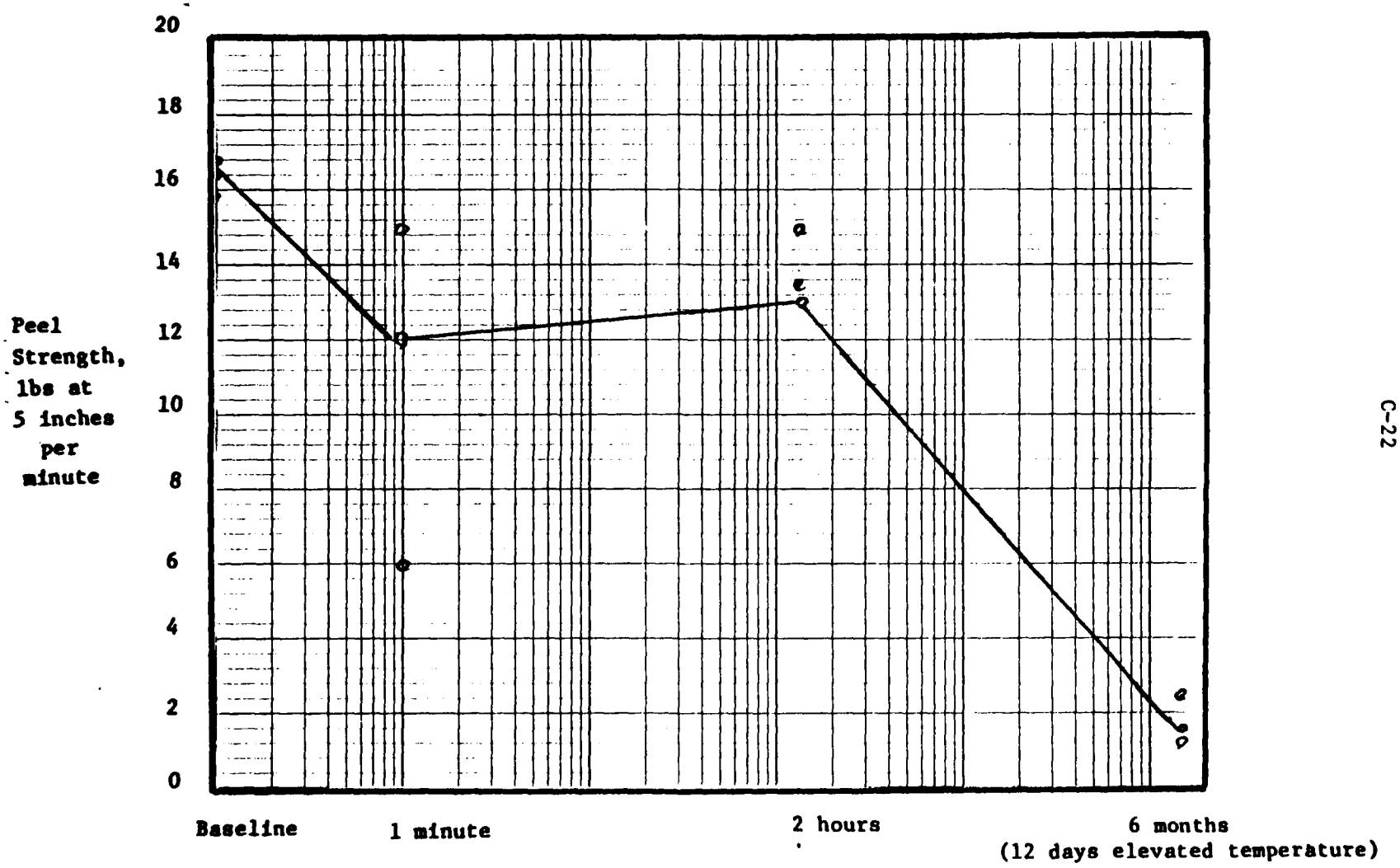
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Ethyl silicate

Figure C-19.



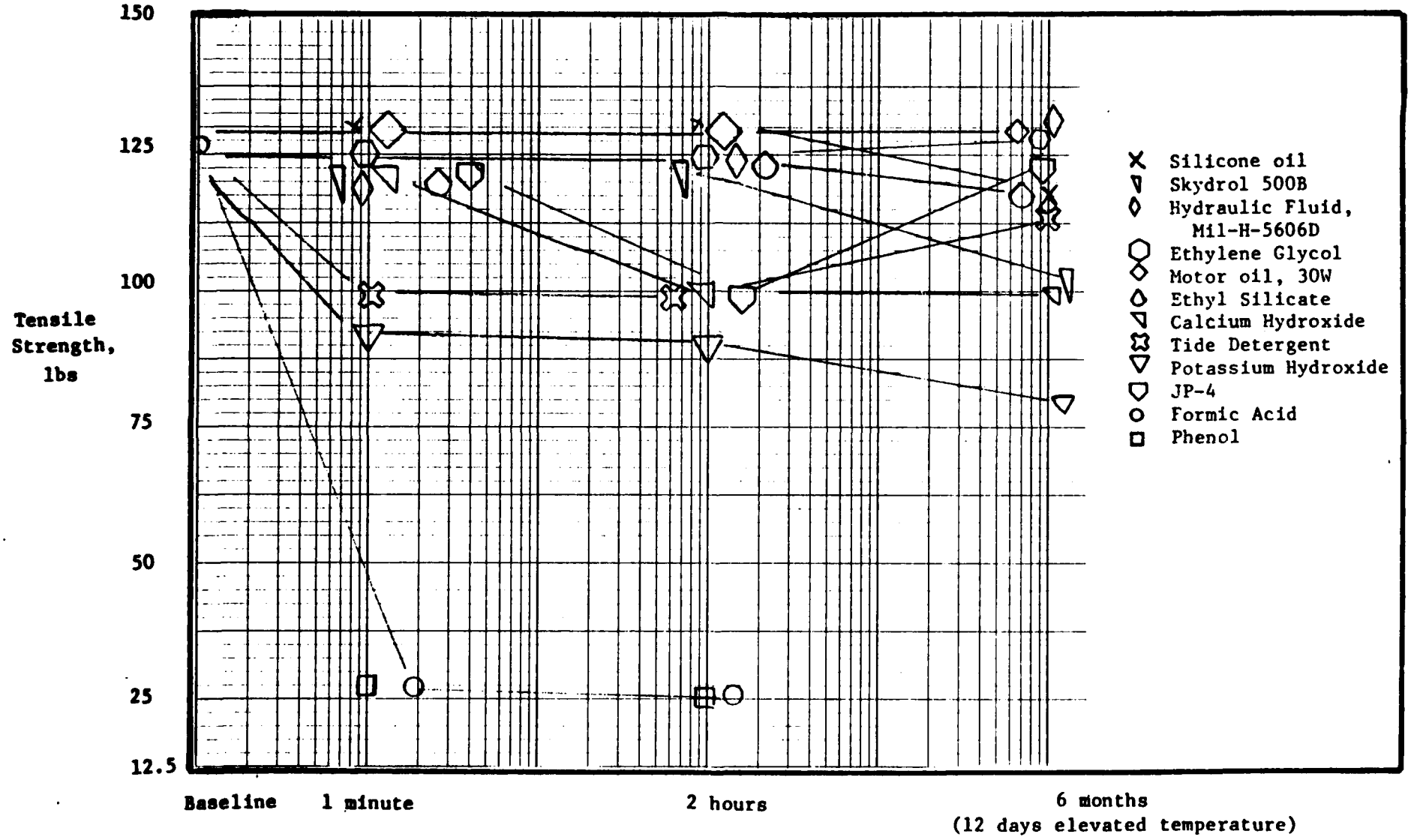
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Skydrol 500B

Figure C-20.



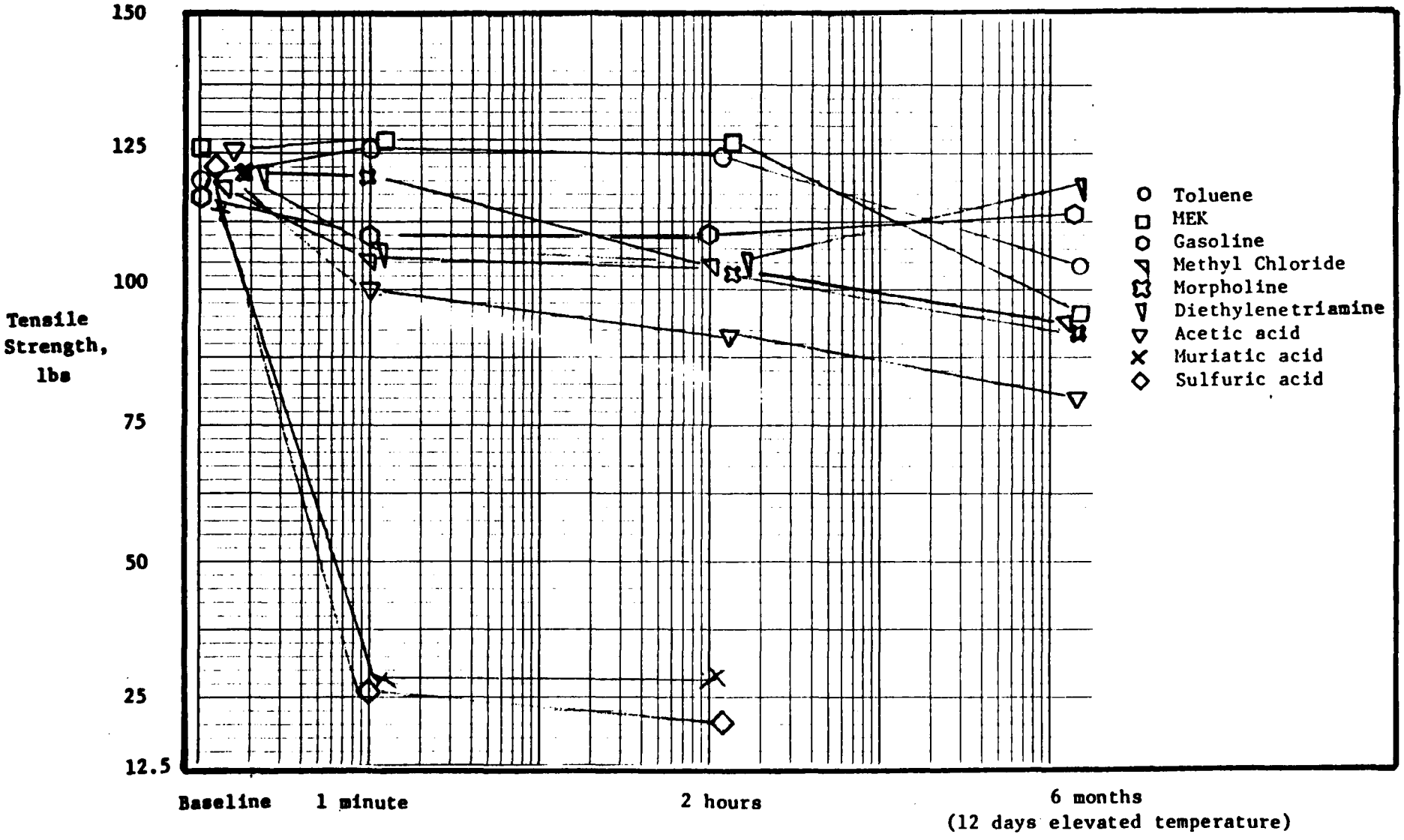
NON-SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: Tide/water

Figure C-21.



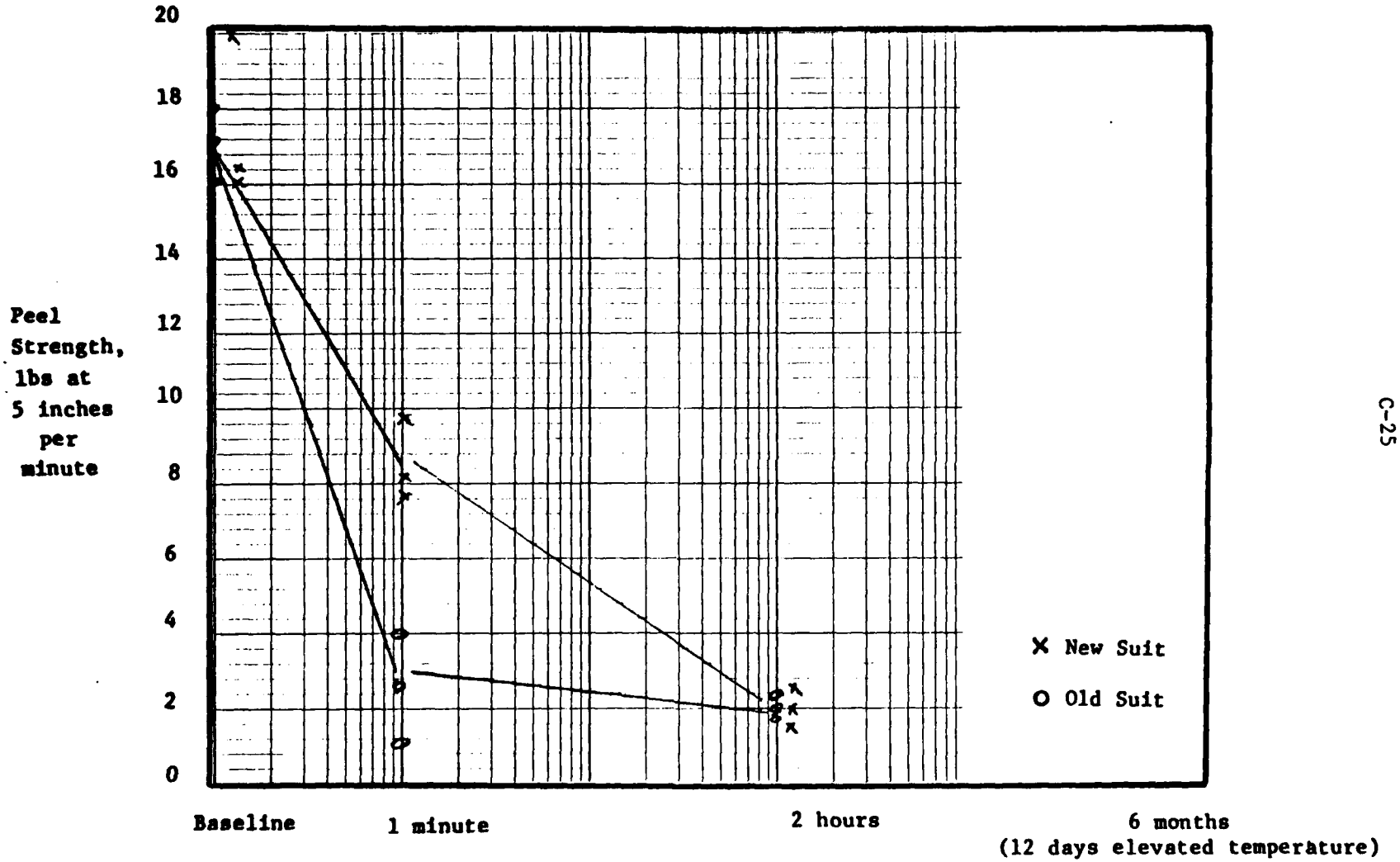
NON-SEAMED CF 200 TENSILE STRENGTH VS LOG TIME

Figure C-22.



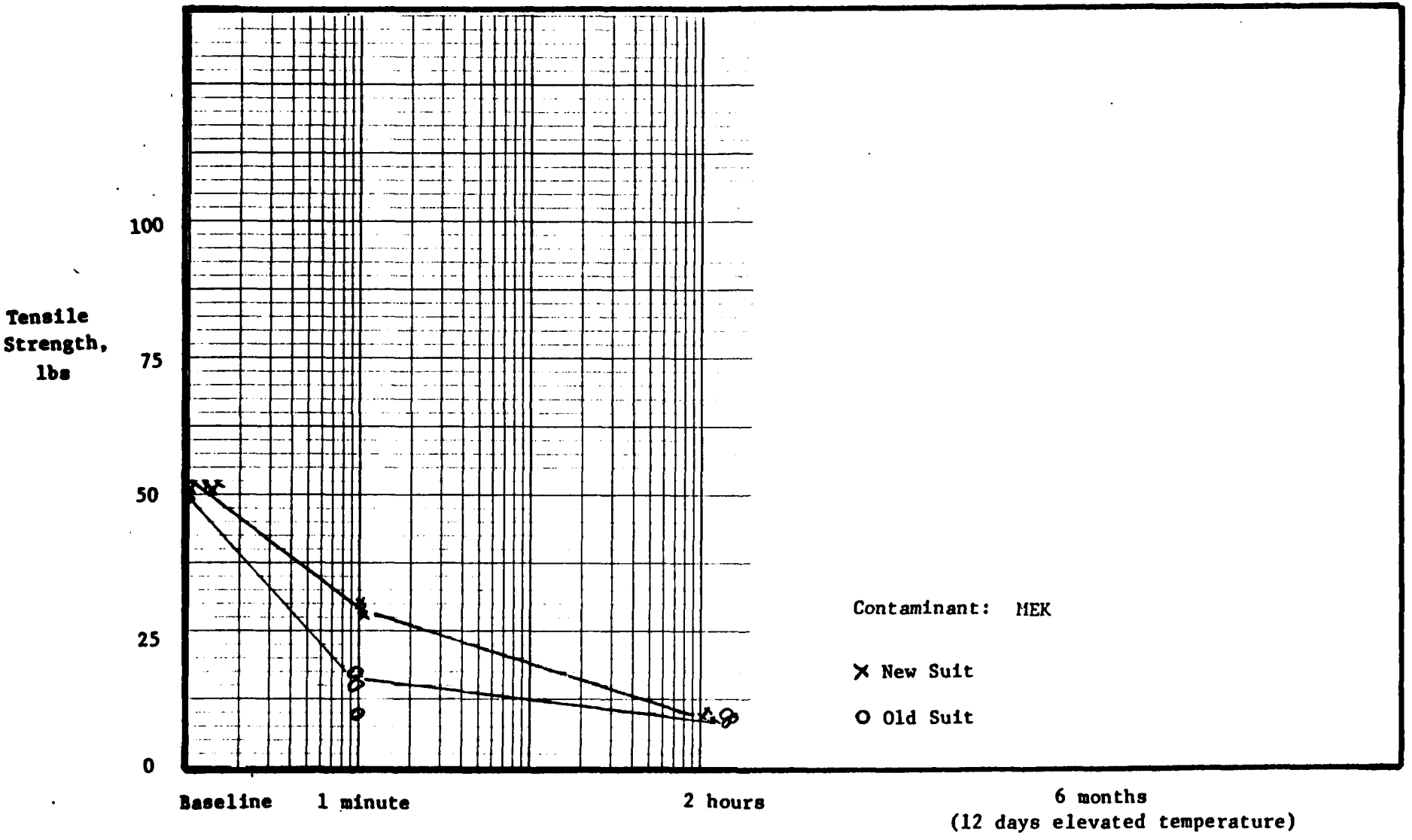
NON-SEAMED CF 200 TENSILE STRENGTH VS LOG TIME

Figure C-23.



SEAMED CF 200 PEEL STRENGTH VS LOG TIME
Contaminant: MEK

Figure C-24.



SEAMED CF 200 TENSILE STRENGTH VS LOG TIME

Figure C-25.